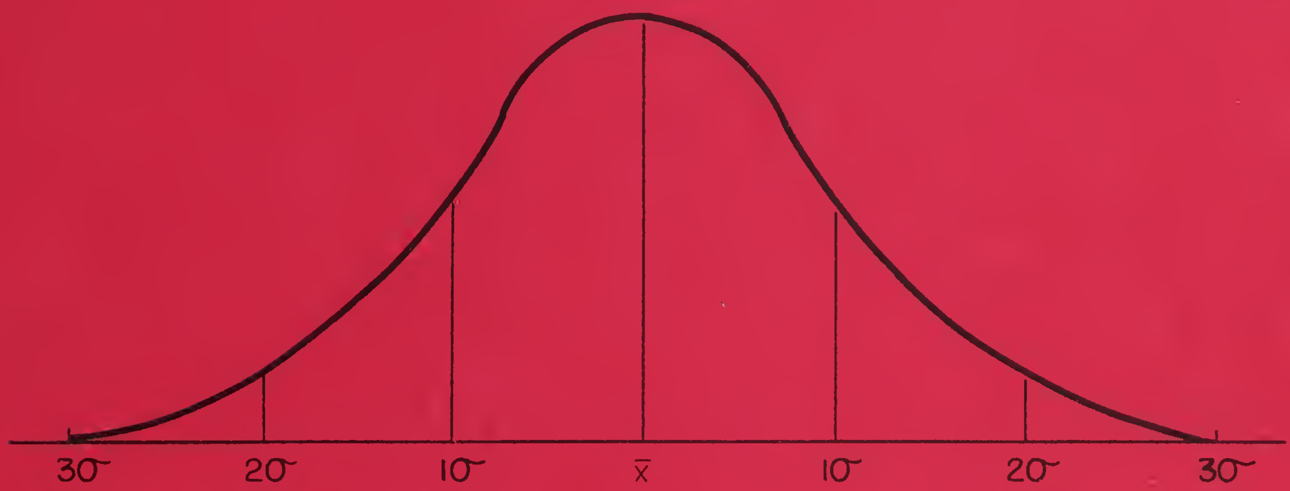
A STATISTICAL ANALYSIS OF TYPE 3 PLANT MIX BITUMINOUS SURFACING FOR QUALITY CONTROL



MONTANA HIGHWAY RESEARCH PROJECT
IN COOPERATION WITH THE
BUREAU OF PUBLIC ROADS

STATE OF MONTANA
HIGHWAY COMMISSION

STATISTICAL QUALITY CONTROL OF
PLANT MIX BITUMINOUS SURFACING

by

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STATE OF MONTANA

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Plant Mix Bituminous Surfacing Quality Control Research

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IDENTIFICATION OF TERMS

1. Analysis of Variance -- A statistical method of isolating causes of variations.
2. Bias -- A constant error, in one direction, that causes the mean to be offset from the true value.
3. Confidence Limits -- Percent of assurance that the true mean, μ, will lie within this distance specified from sample average, $\bar{x}_s$, calculated.
4. Duplicate Sample -- Two portions of material taken at the same time and place, which are as nearly identical as possible.
5. Homogeneity -- Two or more factors having identical characteristics.
6. Level of Significance -- A term used to define the probability that two sample averages estimate a common true mean in a statistical comparison.
7. Lot (or Population) -- A measured amount of material or construction produced by the same process. A project or selected portion of a project constructed under the same specifications.
8. Linear Correlation -- The linear relationship between two variables.
9. Mean -- The arithmetic average found by adding all study values and dividing the total by the number of values used.
10. Null Hypothesis -- (symbol, H_o) A statement of the characteristics being studied under the assumption they are true when H_o is accepted.
11. Optimum Sampling Position -- The position in the production process of a unit of material where sampling will give the best estimate of the overall material.
12. Population Average -- (symbol, μ) The average or mean value of the entire population.

13. Precision -- The variance of repeated measurements of a characteristic from their average.

14. Prediction -- An estimate of a future measurement.

15. Probability Control -- Control over the material such that a definite probability or chance of acceptance or rejection is established.

16. Random Sample -- A sampling plan in which each unit of the lot has a known (usually equal) chance of being sampled.

17. Regression Analysis -- A statistical relationship between a dependent and an independent variable.

18. Regression Curve -- The regression analysis expressed graphically as to the relationship between the values of variables.

19. Rejection -- Nonconformance to the standards set down as required for the particular construction. A rejected material is one which contains an excess of inferior product and may constitute partial or total rejection by penalties levied against the contractor.

20. Sample Average -- (symbol, $\bar{x}$) The arithmetic average obtained from the individual sample units. It is an estimate of the population average.

21. Sampling Curve -- The curve formed showing the distribution of the material. This curve is described as the normal or bell-shaped curve.

22. Segregation of Material -- A combination of the various-sized aggregate such that the mixture is not uniform.

23. Significance -- A statistical term defining the degree to which two variables differ under a null hypothesis.

24. Standard Deviation -- (symbol, σ) The square root of the variance. Also, the measurement of the deviations in the sampling distribution.

25. <u>Statistical Analysis</u> -- The use of mathematical comparisons to determine certain characteristics of various factors.

26. <u>Statistical Parameter</u> -- Values such as $\bar{x}$ and σ^2 which are found through analysis.

27. <u>Variance</u> -- (symbol, σ^2) A measure of dispersion.

TABLE OF CONTENTS

Part 1

Part 2

PART 1

SAMPLING POSITION
COMPARISONS ON SELECTED
CHARACTERISTICS

STATE OF MONTANA
DEPARTMENT OF HIGHWAYS

PLANNING SURVEY
RESEARCH BRANCH

PLANT MIX BITUMINOUS SURFACING QUALITY CONTROL RESEARCH

1965

INTRODUCTION

This project has been pursued with a two-fold purpose in mind:

1. To determine the optimum position in the production process from which to procure samples for acceptance testing of the material for the quality control of Bituminous pavement.
2. To revise specifications concerning acceptance testing of Bituminous pavement through statistical methods and probability control.

In order to study these points, sampling of Type 3 Bituminous plant mix was done from a selected project where random samples were obtained from three (3) positions: 1. the truck bed immediately after the mix was dumped from the pugmill discharge; 2. the screw of the paver before it was laid in the finished mat; 3. the finished mat.

The samples were sent to the Highway Department Laboratory in Helena, where they were tested for aggregate gradation, asphalt content and density of the compacted mix. Temperature recordings were compared with the density results to see if any correlation exists between density and the temperature at compaction.

After preliminary statistical analysis on the results of these samples, two other geographically separated projects were chosen to obtain additional

random samples for the second part of the problem. On these projects only the trucks at the pugmill discharge were sampled for the basic information needed for specification writing. Five samples from each project were, however, sampled at all three positions to support or repudiate the results found in the first part of the project.

Various statistical parameters were found which the specifications could be based upon. Statistical tests were made to assure the procedures and analyses used were valid. The average, $\bar{x}$, and standard deviation, σ', are the main parameters needed. Tests for the homogeneity of variances and analysis of variance were used for significance tests of these parameters.

Other factors were considered in the selection of an optimum sampling position. Safety, manpower needed, production stoppage, quality of construction, and additional work and expense due to the sampling position were important in the determination of the conclusions presented.

GEOGRAPHICAL LOCATION OF STUDY POINTS AND JOB INFORMATION

1. Project F-235(25) and (31), Armington - Lewistown, the first project studied was a centrally-located area of the state in flatland terrain. The Lewistown Division was in charge of this project. The contractor was S. Birch & Sons, Inc., from Great Falls, Montana.

The job extended approximately 11 miles eastwardly from Raynesford to Geyser. Two lifts of hot plant mix Bituminous surfacing were laid, giving a total tonnage of over 38,000 tons. Production was quite constant with the contractor producing an average of 190 tons of plant mix per hour. Ten-hour shifts six days each week were utilized by the contractor. The paving was begun June 28, 1964, and completed July 24, 1964.

Equipment used by the contractor included: one Barber-Greene continuous flow hot mix plant, one Barber-Greene paver, ten dump trucks which hauled approximately sixteen tons per load, and various supporting equipment and vehicles.

Samples from this job were shipped to Helena for testing, via Great Northern Freight trucks, from Geyser, Montana.

The source of the crushed aggregate used in this project was Pit Lab. Nos. 246084-092.

2. Project F-264(8), Townsend - White Sulphur Springs, was the second project included in this study. This was a 6-mile project extending east from Townsend. Geographically, this area is near the Rocky Mountain Chain which covers Western Montana. Aggregate was secured from Pit Lab. Nos. 252279-92. The Butte Division of the Highway Department was in charge of this operation. The contractor, Schultz and Lindsey, Inc., of Billings, operated six days per week, working twelve hours per day. Two lifts of

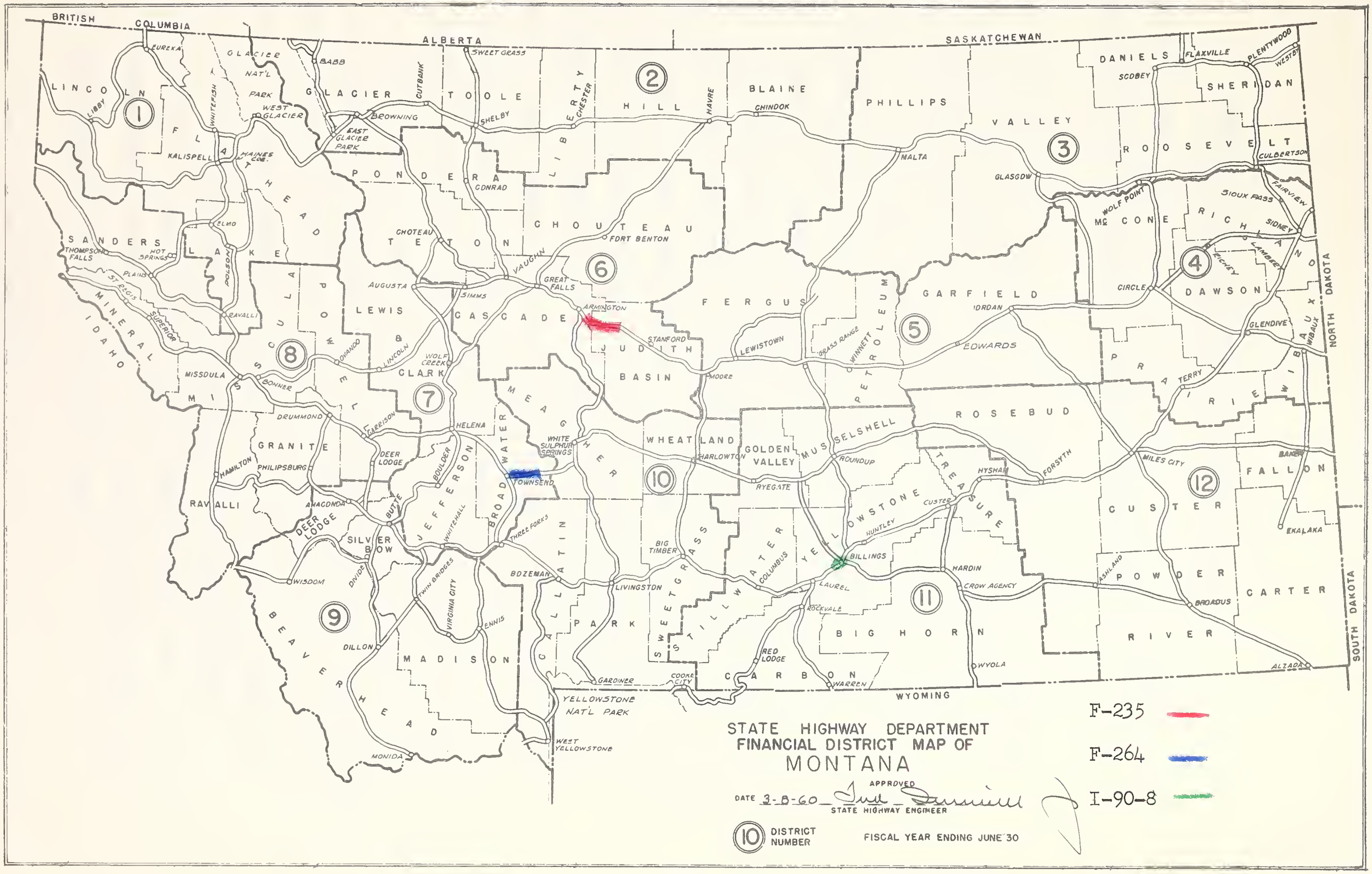
Bituminous plant mix were laid for a total of 24,000 tons of mix at the rate of approximately 250 tons per hour.

The contractor's equipment included: one Cedar Rapids batch plant, one Barber-Greene paver, ten trucks, plus supporting vehicles and equipment. Production was quite constant with this equipment and the paving was completed on August 27, 1964, after two weeks of operation. Samples from this job were delivered to Helena via State-owned vehicles.

3. Project I-90-8(19)443 U-1, West Billings Interchange, the third job studied, was representative of material from the Yellowstone River area. The geographical location is the south central portion of the state. This project was controlled by personnel from the Billings Division with work being contracted by Long Construction Company. Midland Materials of Billings did the paving on the project. Eighty-four hundred (8,400) tons of plant mix were laid during the period sampled from September 11 through September 29, 1964.

The contractor used a Frontier batch plant and five to six trucks in the paving operation. The paver used was a Barber-Greene model. Since the work involved an interchange with numerous small sections, production was sporadic. Two lifts of plant mix were laid. The plant produced at a rate of approximately 125 tons per hour. The contractor worked five days per week in an eight hour shift per day. Materials used were from Pit Lab. Nos. 163584-5.

The samples were delivered to Helena via Northern Pacific Freightways.



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METHOD USED IN THE FIELD TO PROCURE SAMPLES

To obtain samples which were representative of the plant mix being laid and minimize bias in sampling, a method of randomization was employed.

A random number table (see Appendix D, Table T-1) was used to determine when a sample was to be taken. Fifty numbers were chosen by randomly selecting a starting point from the table with a pencil while not looking at the table. The three-digit number nearest to the pencil point was not recorded but the first digit was looked at and used to locate the first three-digit number to be recorded. The value of this first digit was used to count off that many three-digit numbers in any direction: up, down, left or right. The numbers arrived at are recorded and the first digit here is used as the number of three digit values to be counted off, again in any direction, before recording the next number. The process is repeated until all fifty numbers are selected. If the edge of the column or row was reached before the count was completed, the row or column next to this row or column was used as in the manner of reading a page in a book.

For example, in Table T-1, assume the three-digit number .751 in column 7, row 11, was selected at random as a beginning point. Then a count to 7 was started, say downward, to the value .925. This value is recorded. Then counting off 9 numbers, say to the right, we arrive at our next value, .313, by counting to the end of the present row then moving down to the next row and completing the count from the left-hand side to the right. This was continued, then, counting three numbers in any direction and recording the value and so on until all 50 values were obtained. If any ties occurred, another number was selected by continuing the procedure to the 51st number.

When all the random numbers were selected, they were arranged in ascending order and then each number was multiplied by the total lot (pounds or tons) to be sampled. The values arrived at were used as the guide for determining the truck to be sampled. When a sample should be obtained, for example, at 2350 tons of mix, the truck which was carrying the tonnage to reach this total was used to obtain that particular sample.

When sampling from the truck, duplicate samples were obtained in the following manner. One duplicate was secured from a pile of mix dumped from the discharge, on a line perpendicular from top to bottom of the pile. Three scoopfuls of plant mix were obtained, one from near the apex, one near the middle and one near the bottom of the pile (Figure A). These were all placed in one container large enough to hold the three scoops of material. The second duplicate portion was taken in the same manner from the sample pile but 120 degrees to the right or left of the first duplicate sample (Figure B).

Figure A

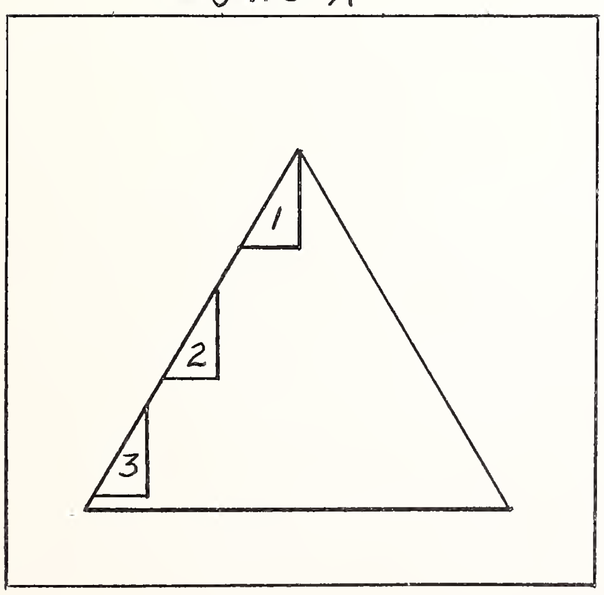
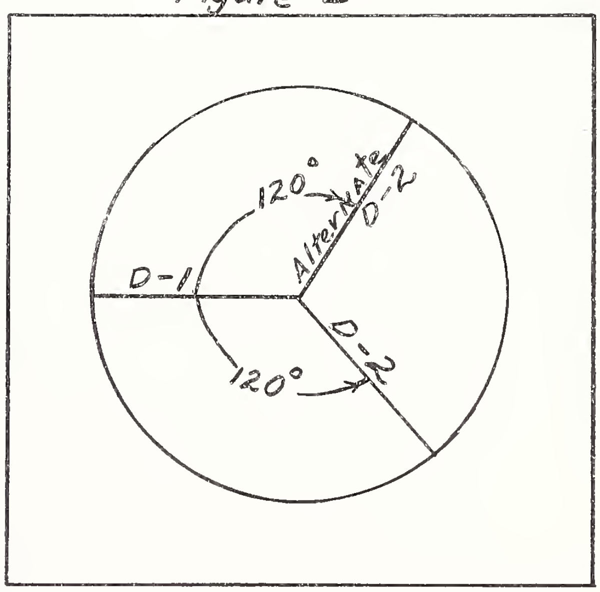


Figure B



From the screw of the paver, samples were obtained from the outer end of the screw. Three consecutive scoops were used to make up each duplicate, taking all the material by pushing the scoop into the plant mix flat on the surface over which the mix was being laid. The side of the paver from which the sample was secured was alternated randomly.

Samples from the finished pavement were obtained by picking an area approximately three feet square. Each duplicate was scooped from a quarter of the area. The quarter to be used for a duplicate was randomly selected. The samples consisted of the entire depth of the lift being laid.

After being thoroughly mixed in accordance with AASHO T-168 to assure consistency between the test portions within each duplicate, the sample was split into two portions. These portions were then placed in sample bags and appropriately numbered to distinguish between the splittings of each duplicate made.

TESTING OF SAMPLES

Extraction

All sample portions were submitted to extraction by reflux method, AASHO T-170. The testing was accomplished by the regular testing personnel with no extra attention or performance required. Standard specification size screens were used for determination of the aggregate gradations studied and the percentages were based on 100 percent aggregate, the asphalt added. Asphalt content was determined by arithmetic computations from weight differences in the sample material before and after extraction.

Also computed for the purpose of revising or developing new specifications were the dust ratio and the -4 + 10 mesh size material.

Density and Immersion Compression

Testing was done in accordance with AASHO manual for density of core samples and immersion compression of material for one project only.

The purpose of this testing was to study the relationships with known and measured material and factors governing density and compressive strength as well as to establish individual job variation of results obtained.

Analysis of these test results to produce a correlation with aggregate gradation and asphalt content was attempted, plus correlation between factors involved in determining these test results.

INTERPRETATION OF RESULTS

In the statistical analysis, the findings are expressed in terms of "significant differences" between the sampling position average or "nonsignificance", depending upon the test results.

As a format to the body of this report, an explanation of the meaning of these terms is presented.

In the tests of the null hypothesis (H_O: No difference exists between position averages), an effort is made to determine whether the separate sampling positions have a common true mean or that they will have different true means, not equal to each other.

When significance is claimed between sampling position averages, the conclusion assumed is that the difference between the sample averages is such that if the null hypothesis is true, a difference between the compared averages this large or larger is likely to occur only 5 percent of the time. If a conclusion of "highly significant differences" existing results, it is assumed that a difference this large will result 1 percent of the time if the null hypothesis is true.

With the small probability of the null hypothesis being true in these cases, the alternate conclusion arrived at is that the position true means are not equal. The samples from the separate positions estimate different theoretical mean values. Thus, if significance is claimed, it is presumed that the null hypothesis is false. Under this assumption, if sampling is accomplished at one sampling position, the results will be different than if this same material is sampled at another position.

STUDY ON THE GRADATION OF AGGREGATE

The study to determine the optimum position from which to obtain samples of Type 3 Bituminous asphalt paving material has brought forward valuable and interesting results.

Empirical results have been obtained by comparing the three sampling positions stated as those best suited for sampling. The elements involved in the comparisons were the average values for each of the several aggregate sizes and asphalt content at each sampling position plus the variation in the sampling and testing procedures and the actual material variation about the mean (average).

The main purpose of the investigation was to determine the extent the sampling position affected the values of the results obtained.

In presenting conclusions, significance between the averages was based on a predetermined percent of probability that the samples obtained from the three positions have the same true mean (μ); i.e., that regardless of sampling position, the sample averages will be the same except for small differences present due to random variation in the normal construction process.

Testing for significant differences in the analysis for homogeneity of variances indicates whether the variability of the material at one of the sampling positions is theoretically the same as, or different from, the variation at one of the other sampling positions. A conclusion that a significant difference does exist is dependent upon a ratio of two position variances (σ^2). This ratio $F = \sigma_1^2 / \sigma_2^2$ (σ_1^2 being the larger) gives a numerical value greater than or equal to one which is compared to a table in order to conclude that the two variances are either homogeneous or one

variance is truly larger than the other. The latter conclusion indicates that at a given position the samples will have a wider spread in values about its average than will the other position in the comparison about its average.

The portion of variance attributable to sampling procedure is of great importance in this study. This is reasoned by the fact that this is the portion most likely to fluctuate between the different sampling positions since for the other components: 1. all samples, regardless of position, are tested in the same manner; 2. the material variation cannot be controlled by the person sampling and will be present in the process at every sampling position.

Relationship Between the Position Averages

Comparisons between the averages computed for each of the three sampling positions exhibit definite trends on all three of the selected projects.

Table 1 gives the average aggregate percentages passing the several mesh screens. In all cases where a significant difference between the average values of the three sampling positions does exist and in the majority of cases not claimed significant, a larger percent passing a particular mesh screen is shown at the pugmill discharge than at the screw of the paver and the finished mat. The least percent passing a given screen is consistently evident for the averages of samples taken at the finished pavement. Thus, this statement implies a greater percentage of intermediate material to be present in samples from the pugmill discharge than is indicated in corresponding samples from the other two sampling positions until the 40 mesh screen is reached. At this screen

TABLE 1

Average Values of Percentage by Weight of Aggregate Passing Sizing Screens.

F-235(25) & (31)

	Sampling Position			Significance between Means	
Mesh	Discharge	Paver	Pavement	RCB	CR
3/4"	100	100	100	N.S.	N.S.
1/2"	96.92	96.94	96.42	H.S.	H.S.
3/8"	85.28	83.54	83.12	H.S.	H.S.
4	58.78	56.52	55.65	H.S.	H.S.
10	37.38	35.73	35.26	H.S.	H.S.
40	15.18	14.69	14.74	H.S.	N.S.
80	8.40	8.25	8.39	N.S.	N.S.
200	5.96	5.84	5.98	N.S.	N.S.

F-264(8)

	Sampling Position			Significance between Means
Mesh	Discharge	Paver	Pavement	
3/4"	100	100	100	N.S.
1/2"	96.25	95.69	95.51	N.S.
3/8"	78.21	76.70	75.90	N.S.
4	55.19	54.38	53.38	N.S.
10	42.46	41.67	40.92	N.S.
40	25.33	25.49	24.90	N.S.
80	11.48	11.79	11.34	N.S.
200	6.62	6.99	6.74	N.S.

I-90-8(19)443 U-1

	Sampling Position			Significance between Means
Mesh	Discharge	Paver	Pavement	
3/4"	100	100	100	N.S.
1/2"	96.41	95.91	96.00	N.S.
3/8"	84.85	83.51	83.52	N.S.
4	64.35	63.60	63.17	N.S.
10	42.98	43.36	43.07	N.S.
40	20.65	20.28	20.40	N.S.
80	10.39	10.40	10.29	N.S.
200	6.69	6.63	6.59	N.S.

and below, the percentages of material passing are the same for all three positions. Samples from the finished pavement indicate the least amount of intermediate material present.

Highly significant differences were claimed between the averages of the three sampling positions for the larger mesh screens on samples from the initial project (see Table 1). Significance was not claimed between position averages from the two additional studies, possibly due to the less restrictive limits allowable since fewer samples were obtained for analysis. Since the same trend of the averages, referred to earlier, was present, it might be that an insufficient number of samples were obtained to declare significance between the averages even though it actually exists.

The statistical analysis was made to test the null hypothesis; no significant difference exists between the mean values of the samples obtained at the pugmill discharge, screw of the paver and the finished pavement when these positions are used as a basis for the logical places from which to acquire acceptance samples. By rejecting the hypothesis, a difference between the theoretical means of the sampling positions is claimed. When this results, sample averages are said to estimate separate theoretical means but, if the hypothesis is not rejected, the sample averages are assumed to all be estimates of one true mean value.

A 0.5 percent or less difference is found between position averages at the percent passing the 1/2 inch, 40, 80 and 200 mesh screens. The largest difference, 3.2 percent, is found at the percent passing the 40 mesh screen, indicating greater fluctuation in the intermediate size aggregate between sampling positions. This type of fluctuation is followed closely in the two additional projects studied.

Rejection of the null hypothesis at the 1 percent level of significance was done for the following list mesh screen sizes: 1/2 inch, 3/8 inch, 4 mesh and 10 mesh. The null hypothesis was not rejected at the 3/4 inch, 40 mesh, 80 mesh and 200 mesh screens.

The resulting averages of the four screens included in the rejected category above will depend upon the position from which the samples are obtained while, for the four screen sizes accepted under the null hypothesis, the averages obtained will not depend upon the sampling position. The position averages for each of the 3/4 inch, 40, 80 and 200 mesh screens are estimates of a single true mean, , whereas, for the former set of screens, the computed averages are estimates of individual position means; i.e., it must be concluded here that each position of sampling has its own parameter, μ, about which the populations of mixed material will vary and is different from at least one of the other position's population and mean value. This reveals that the results obtained by testing the aggregate is dependent upon the position from which the samples were obtained for screen sizes 10-mesh and larger and the results will be different for a given material when sampled at two different positions.

A factor worth discussing is the trend of the averages previously presented. Since a trend of less percent passing a screen is developed from the pugmill discharge to the pavement on all the projects studied, it seems a logical reason might be established.

At the screw of the paver, samples could only be obtained from the end of the auger. Thus, the thought is aroused of segregation of materials as the auger pushes them toward the ends where the sampling is

accomplished. In this distance of five to six feet, the larger material would have a better chance of being retained by the auger and pushed to the ends. A larger amount of 3/8 inch and 4 mesh material would be present in a sample taken here than one taken at the pugmill discharge.

Samples from the finished pavement contained a greater amount of 3/8 inch and 4 mesh material than either of the other positions. This might be accounted for by the fact that: 1. the samples were taken near the edge of the mat, since sampling near the center is prohibitive because of the heat of the material and the difficulty in repairing the mat. They will contain, therefore, much the same percentages as samples from the end paver auger; 2. small irregularities in the base surface are filled by fine material and are not present in the sample, thus lowering the percent of material passing the larger screens, since the fine material is replaced in percentage by coarser aggregate.

Since sampling at the pugmill discharge from the truck beds was done at various places in the plant mix pile and at three different heights, no logical explanation of segregation occurring could be found here.

Although it is nice to theorize why, where and if segregation of material did occur, the fact remains that the material for the roadway does not change in consistency as a whole from the time it is dumped into the truck bed until it is in the finished mat except for a minute amount of crushing during the process. The ideal sampling process should present a good picture of the overall roadway. High precision, with a minimum amount of sampling, is desirable. The less variable a factor is, the fewer samples required for an estimate with a given precision. A less variable factor will give a more precise estimate than a highly variable

factor with an equal number of samples of each factor. An example to point out this fact is given later.

This relationship leads into another important consideration, this being the measure of variability at each sampling position.

Comparing Sampling Position Variability

The factors involved in the study of the variation at each aggregate size required taking duplicate samples and splitting each duplicate for testing. The purpose of this was to study error in the sampling and the testing processes as well as material variation.

A breakdown of the components of the variation for each sampling position was accomplished. This breakdown is shown in Table 2, along with the overall variance, σ'^2.

Analyzing the breakdown statistically for significantly large differences between the variance components of the three sampling positions provided information valuable to the study.

In analyzing σ_t^2 (testing variation) (see Table 2a), significance was claimed for two mesh screens, the percent passing the 1/2 inch and 200 mesh screens. At the 1/2 inch screen the pavement samples were determined to have greater variation than either the pugmill discharge or the screw of the paver samples. No difference was claimed for σ_t^2 between the discharge and paver samples. At the 200 mesh screen the σ_t^2 observed at the discharge was greater than at the finished mat but not the paver. The samples from the paver were observed to have a larger σ_t^2 than at the finished pavement. All of the other comparisons were claimed to have the same theoretical σ_t^2 and differences between them are the result of randomization.

From the projects studied to further substantiate the initial findings, much the same sporadic claims of significance resulted. This, in effect, demonstrates that the testing variance cannot be categorized as having a larger variance due to testing error at any particular sampling position. This should be true since all samples are tested in an identical manner.

The variance component attributable to sampling error is given in Table 2b. Statistical comparisons between the samples from the discharge and the paver indicate the sampling variance component is significantly larger at the screw of the paver for all screen sizes except the 80 and 200 mesh screens. No difference between sampling variances exists at these two screens. The σ_s^2 (sampling variance) from the screw of the paver was claimed to be significantly larger than at the finished mat at all screen sizes. Comparing σ_s^2 between the pugmill discharge and the finished pavement, it is seen that the percent of material passing the 1/2 inch and 3/8 inch screens is more variable at the finished pavement while at the smaller mesh screens the samples from the pugmill discharge are more variable.

All σ_s^2 values for the pugmill discharge and the finished pavement are extremely small or zero. Samples obtained from these two positions will be influenced only to a small degree by any variation in an individual sampler's method of obtaining a sample specimen, whereas samples obtained from the screw of the paver vary to a large extent due to sampling error. Sampling error refers to variation in the material within a small area of pavement or with the material in a truck at the discharge. It does not imply a sampler may be careless in taking a sample and that no appreciable variation will occur.

TABLE 2

Variance Components of the Aggregate Gradations

F-235(25) & (31)

(a) Testing (σ_t^2) — (b) Sampling (σ_s^2)

Mesh	Discharge	Paver	Pavement	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00	0.00	0.00	0.00
1/2"	0.77	0.71	1.20*	0.09	0.53	0.11*
3/8"	2.85	2.75	3.64	0.00	2.00	0.19*
4	3.50	3.68	4.63	0.00	2.20	0.00*
10	1.54	1.15	1.68	0.00	5.92	0.00*
40	0.63	0.46	0.43	0.13	0.38	0.00*
80	0.51	0.43	0.35	0.15	0.19	0.00*
200	0.74	0.55	0.36*	0.18	0.29	0.00*

(a) $F_{.01} = 1.70$ $F_{.05} = 1.51$ — (b) $F_{.01} = 2.13$ $F_{.05} = 1.77$

(c) Material (σ_a^2) — (d) Overall ($\sigma'^2 = \sigma_t^2 + \sigma_s^2 + \sigma_a^2$)

Mesh	Discharge	Paver	Pavement	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00	0.00	0.00	0.00
1/2"	0.03	0.21	0.06*	0.89	1.45	1.37*
3/8"	0.34	4.35	2.42*	3.19	9.10	6.25*
4	2.59	7.27	4.91*	6.09	13.15	9.54*
10	3.54	0.00	4.45*	5.08	7.07	6.13*
40	1.00	1.15	1.42	1.76	1.99	1.85
80	0.68	0.71	0.86	1.34	1.33	1.21
200	0.74	0.62	0.80	1.66	1.46	1.16*

(c) $F_{.01} = 2.14$ $F_{.05} = 1.78$ — (d) $F_{.01} = 1.50$ $F_{.05} = 1.35$

* Indicates significant differences exist in comparisons of the components at these mesh screen sizes.

TABLE 2 (cont.)

F-264(8)

(a) Testing (σ_t^2)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	1.55	0.62	1.05
3/8"	3.55	2.61	4.14
4	3.12	2.13	2.11
10	2.90	0.96	1.39
40	1.73	0.56	1.18
80	0.88	0.46	1.33
200	0.75	0.20	1.30*

$F_{.01}(100,10) = 4.79$ $F_{.05}(100,10) = 3.16$
$F_{.01}(10,100) = 2.78$ $F_{.05}(10,100) = 2.20$
$F_{.01}(10,10) = 5.85$ $F_{.05}(10,10) = 3.72$

(b) Sampling (σ_s^2)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	0.00	0.53	0.15*
3/8"	0.07	3.39	0.00*
4	0.22	1.38	0.18*
10	0.10	1.38	0.06*
40	0.08	0.60	0.13*
80	0.08	0.14	0.00*
200	0.18	0.53	0.00*

$F_{.01}(50,5) = 12.47$ $F_{.05}(50,5) = 6.15$
$F_{.01}(5,50) = 3.88$ $F_{.05}(5,50) = 2.85$
$F_{.01}(5,5) = 14.92$ $F_{.05}(5,5) = 7.15$

(c) Material (σ_a^2)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	0.46	0.43	0.56
3/8"	4.24	0.67	15.72*
4	10.56	4.29	19.75
10	12.56	4.34	14.53
40	4.95	2.66	6.09
80	1.15	0.92	1.18
200	0.77	0.51	1.54

$F_{.01}(49,4) = 19.68$ $F_{.05}(49,4) = 8.38$
$F_{.01}(4,49) = 4.25$ $F_{.05}(4,49) = 3.07$
$F_{.01}(4,4) = 23.15$ $F_{.05}(4,4) = 9.60$

(d) Overall ($\sigma'^2 = \sigma_t^2 + \sigma_s^2 + \sigma_a^2$)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	2.01	1.58	1.76
3/8"	7.86	6.67	19.86*
4	13.90	7.80	22.04*
10	15.56	6.68	15.98*
40	6.76	3.82	7.40
80	2.11	1.52	2.51
200	1.70	1.24	1.84

$F_{.01}(199,19) = 2.87$ $F_{.05}(199,19) = 2.17$
$F_{.01}(19,199) = 2.12$ $F_{.05}(19,199) = 1.77$
$F_{.01}(19,19) = 3.40$ $F_{.05}(19,19) = 2.51$

TABLE 2 (cont.)

I-90-8(19)443 U-1

	(a) Testing (σ_t^2)			(b) Sampling (σ_s^2)		
Mesh	Discharge	Paver	Pavement	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00	0.00	0.00	0.00
1/2"	1.09	1.63	0.88	0.00	0.00	0.00
3/8"	2.09	3.33	1.22	0.00	0.00	0.88*
4	2.11	3.30	1.11	0.00	0.00	0.33*
10	0.88	1.45	0.37*	0.15	0.00	0.16*
40	1.00	1.83	0.48*	0.00	0.00	0.12*
80	0.66	0.16	0.06*	0.24	0.00	0.11*
200	0.50	0.07	0.04*	0.33	0.00	0.04*

	(c) Material (σ_a^2)			(d) Overall ($\sigma'^2 = \sigma_t^2 + \sigma_s^2 + \sigma_a^2$)		
Mesh	Discharge	Paver	Pavement	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00	0.00	0.00	0.00
1/2"	0.69	1.03	0.30	1.78	2.66	1.18
3/8"	6.42	3.80	0.00*	8.51	7.13	2.10*
4	1.58	5.24	2.02*	3.69	8.54	3.46*
10	5.27	8.19	5.66	6.30	9.64	6.19
40	3.55	1.36	2.16	4.55	3.19	2.76
80	1.45	1.36	1.76	2.35	1.52	1.93
200	1.22	1.62	1.76	2.05	1.69	1.87

On the additional studies, F-264, The $\sigma_s'^2$ followed the initial project closely while I-90 did not but showed very little variation due to sampling at all sampling positions. (See Table 2 for F-264 and I-90).

Material Variation

Table 2c shows the variation associated with fluctuation in the material from sample to sample which cannot be attributed to either the sampling or testing processes. Significant differences in the variation of the material occurred at the 1/2 inch, 3/8 inch, 4 and 10 mesh screens. The small aggregate (40, 80 and 200 mesh) disclosed no significant difference in the theoretical material variation between the three sampling positions.

The material varied about the individual position average more at the screw of the paver than at either the pugmill discharge or the finished mat except in the 10 mesh comparison. However, it is probable the zero material variation recorded at the paver for this screen is caused by a concealing effect of any variation here due to the large $\sigma_s'^2$ associated with the paver. (See Table 2).

The samples from the finished mat showed more variation than those taken at the pugmill discharge at the 1/2 inch, 3/8 inch and 4 mesh screens. At all other screen sizes the variations were theoretical estimates of a common true variance. The sampling position exhibiting the least amount of variation in the material is concluded to be the pugmill discharge after the material is dumped into the truck beds.

Overall Variation $\sigma_t'^2 + \sigma_s'^2 + \sigma_a'^2 = \sigma'^2$

The overall variance σ'^2 (see Table 2d) is the summation of the components which contribute to the variation of a sample from the average.

It takes into account errors caused in testing, $\sigma_t'^2$; sampling, $\sigma_s'^2$; and, $\sigma_a'^2$, the variation in the material over the lot sampled. σ'^2 is the parameter which, with $\bar{x}$, gives the distribution of the material in the project sampled. The curve obtained from these parameters gives the expected distribution of the samples about the average computed for the material (see Figure 1). The symmetrical shape of the curve shows 50 percent of the material to lie on each side of the average. It also indicates by the area under the curve that the further away from the average, in either direction, the fewer the number of samples will be obtained with these values observed on the scale.

Significantly larger σ'^2 values are evident at the screw of the paver than at the pugmill discharge for the 1/2 inch, 3/8 inch, 4 and 10 mesh screens. At the 40, 80 and 200 mesh screens no theoretical differences in the σ'^2 of these two positions were concluded. The samples from the finished pavement have greater variation than samples from the pugmill discharge at the 1/2 inch, 3/8 inch and 4 mesh screens. The variation at the 200 mesh screen was larger at the pugmill discharge.

Comparison between the samples at the screw of the paver and the finished pavement showed only the 3/8 inch and 4 mesh screens to be different in the respective overall variations. The paver samples have the larger variation in both cases.

Standard Deviation

In Table 3, the standard deviation σ' of the distributions are recorded. The standard deviation is defined as the square root of the variance and is used in constructing the normal (bell shaped) sampling distribution curves (see Figure 1). Each curve is symmetrical about its

TABLE 3

Standard Deviations Calculated from the Variance for Aggregate Gradation

F-235(25) & (31)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	0.94	1.20	1.17
3/8"	1.79	3.02	2.50
4	2.47	3.62	3.09
10	2.25	2.66	2.50
40	1.33	1.42	1.36
80	1.16	1.15	1.10
200	1.29	1.21	1.08

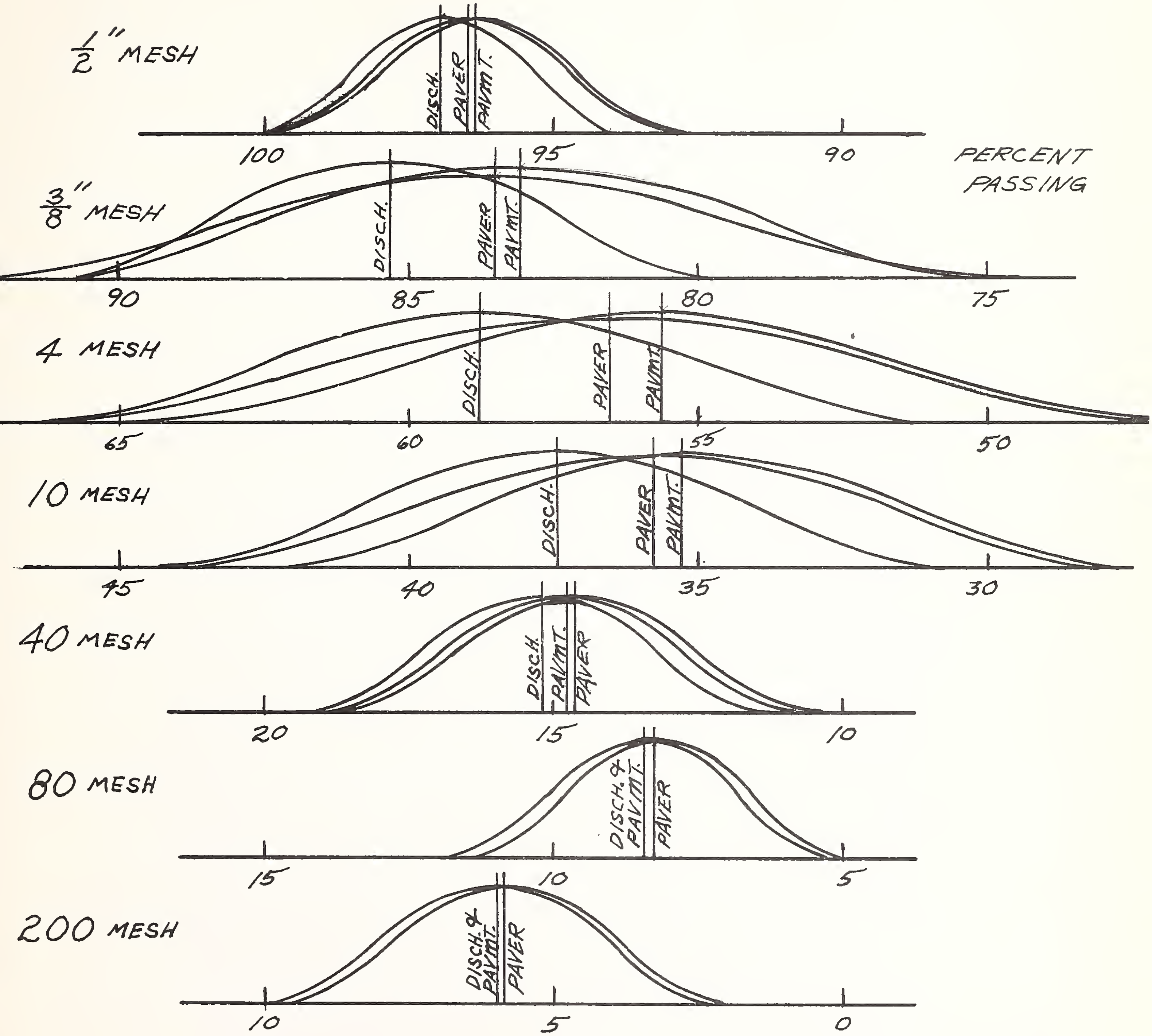
F-264(8)

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	0.94	1.20	1.17
3/8"	2.80	2.58	4.46
4	3.73	2.79	4.70
10	3.95	2.58	4.00
40	2.60	1.95	2.72
80	1.45	1.23	1.58
200	1.30	1.11	1.36

I-90-8(19)443 U-1

Mesh	Discharge	Paver	Pavement
3/4"	0.00	0.00	0.00
1/2"	1.33	1.63	1.09
3/8"	2.92	2.67	1.45
4	1.92	2.92	1.86
10	2.51	3.10	2.49
40	2.13	1.79	1.66
80	1.53	1.23	1.39
200	1.43	1.30	1.37

FIGURE 1 MATERIAL DISTRIBUTION OF AGGREGATE



COMPARISONS BETWEEN SAMPLING POSITIONS FOR THE PERCENT PASSING THE INDIVIDUAL SIZING SCREENS ON MATERIAL FROM PROJECT F-235 (25) & (31).

respective average, $\bar{x}$, and, for all practical purposes, ranges from $\bar{x} - 3\sigma'$ to $\bar{x} + 3\sigma'$ within which 99.7 percent of the sample values obtained from the lot will lie. If a sample value is obtained which falls beyond the prescribed end points of the curve ($\pm 3\sigma'$) one of two possibilities has occurred: 1. a value from this distribution $N(\bar{x}, \sigma')$ having a 0.15 percent chance of being found, has been selected; 2. this value indicates another distribution having a different set of parameters $\bar{x}_2$ and σ'_2 forming a new curve within which this observed value is contained.

Figure 1 visually explains how the differences in variability between the sampling positions affects the shape of each curve. At the screen sizes concluded to have no significant differences in σ'^2, the shape of the curves are close to being identical but, where significant differences in the variability between the positions resulted, the shape of each is extremely different for a given aggregate gradation.

Mean Deviation

In acceptance sampling it is desirable to minimize the mean deviation, $\sigma_{\bar{x}}'$. A more precise estimate of the true population average is obtained when $\sigma_{\bar{x}}'$ is small. Minimizing $\sigma_{\bar{x}}'$ can be done by either selecting the sampling position with the smallest variance or by procuring a large number of samples. The relationship which makes this possible is $\sigma_{\bar{x}}' = \frac{\sigma'}{n}$.

An example of this follows, using the 3/8 inch screen in Table 3.

Assume four samples from the discharge and four samples from the paver were taken.

For the discharge $\sigma_{\bar{x}} = \frac{\sigma_{x'}}{\sqrt{n}} = \frac{1.79}{2} = 0.89$

For the paver $\sigma_{\bar{x}}' = \frac{\sigma_{x'}}{\sqrt{n}} = \frac{3.02}{2} = 1.51$

In order to lower the deviation of the mean values at the paver to vary within a curve described by $\sigma_{\bar{x}}' = 0.89$ and thus be as precise an estimate as obtained at the discharge, we must take twelve samples as calculated by:

$$\sigma_{\bar{x}}' = \frac{\sigma_{x'}}{\sqrt{n}} \quad \text{or} \quad \sqrt{n} = \frac{\sigma_{x'}}{\sigma_{\bar{x}}'}$$

Thus: $\sqrt{n} = \frac{3.02}{0.89} = 3.39$

therefore, $n = 11.5$ or 12 samples.

To find the average percentage of material passing the 3/8 inch screen on a project, four samples taken at the discharge will estimate "μ" within the same limits as twelve samples taken at the screw of the paver. Therefore, it is more feasible to sample at the discharge.

By studying the significance claimed between overall variances of the three sampling positions on all three projects, it may be concluded that no difference exists between position overall variances on a given project for the percent passing the 40, 80 and 200 mesh screens. At the larger screen sizes significant differences occur between σ'^2 of the positions.

Since F-235(25) and (31), our initial project, was studied more closely, more weight in the evaluation is given to results obtained from the analysis of its data than to the other projects studied. It is concluded the material sampled at the pugmill discharge will have less variation than samples obtained from the screw of the paver or the finished

pavement. The position of sampling where the greatest variation occurred is the screw of the paver. Results substantiate this quite well on the other projects except in one case, this being the variance at the discharge was termed greater than the variance at the screw of the paver at the 5 percent level at the 10 mesh screen on Project F-264(8).

In conclusion for the aggregate gradation analysis, the main problem in selecting a proper and effective sampling position will develop in the mesh screens larger than 40 mesh. The 40, 80 and 200 mesh screens show little dependency upon the position of sampling in the resulting averages and variation obtained and have nearly identical distributions.

For the 10, 4, 3/8 inch and 1/2 inch screen sizes a particular sampling location should be used exclusively, since the sample values and averages obtained will depend upon the position from which the samples were procured.

A specification drawn for one particular sampling position will possibly cause erroneous acceptance or rejection of the product if sampling is done at another position in the process.

The nonhomogeneity of the variances of the sampling positions at the larger size screens affirms the definition of a particular position from which to sample. Properly done, this can reduce the number of samples required and give a sound basis for acceptance or rejection of highway construction materials.

ASPHALT CONTENT

The analysis of the asphalt content in the mixture was completed on the asphalt extracted from the samples and recorded as a percent added to the aggregate. A separate statistical analysis was done for the several bitumen field checks. The bitumen field checks are identified as the amount of asphalt added to the aggregate during a specified period of time, usually a single production day. Individual average values and variances were figured for each different field check recorded.

From the analysis of variance for the asphalt content, Appendix B, of the eight separate field checks, only three claimed significant differences between treatment means to exist. A test to determine which averages were different was accomplished and the results shown in Table 4. The solid line connecting two averages indicate nonsignificance. The average not connected by a line is claimed to be significantly different from the other two, therefore, the hypothesis of no difference between position means is rejected as false.

Looking at the averages found for the various bitumen field checks, it is observed the samples taken at the pugmill discharge correspond closely with the percentage of asphalt which was calculated to be present in the mixture. In most cases, the samples from the other positions indicated less asphalt present in the mixture than was actually calculated by the field check. Thus it is a reasonable assumption that the samples taken at the pugmill discharge will present a better estimate of the actual amount of asphalt used in the production (see Table 5). The other

TABLE 4

Test to Determine Where Significance Lies on 7.1, 6.8, and 6.6 Percent Asphalt Content.

F-235(25) & (31)

7.1%

Discharge	Paver	Pavement	
7.04	6.55	6.49	at .05

P	2	3		2	3
LSR (.050)	0.168	0.176	(.01)	0.228	0.239

6.8%

Discharge	Paver	Pavement	
6.80	6.50	6.50	at .05

P	2	3		2	3
LSR (.05)	0.110	1.120	(.01)	0.153	0.155

6.6%

Discharge	Paver	Pavement	
6.64	6.51	6.33	at .01

P	2	3	2	3
LSR (.05)	0.124	0.130	0.164	0.171

TABLE 5

Average Values of Asphalt Content Recorded for the Individual Bitumen Field Checks

F-235(25) & (31)

BFC	Sampling Position		
	Discharge	Paver	Pavement
7.5	7.3	6.5	7.2
7.3	7.0	6.6	6.9
7.1	7.0	6.5	6.5
7.0	6.7	6.5	6.5
6.9	6.8	6.6	6.5
6.8	6.8	6.5	6.5
6.7	6.6	6.5	6.5
6.6	6.6	6.5	6.3
6.5	6.5	6.4	6.4

F-264(8)

BFC	Sampling Position		
	Discharge	Paver	Pavement
5.7	5.7	5.7	5.7

I-90-8(19)443 U-1

BFC	Sampling Position		
	Discharge	Paver	Pavement
5.5	5.5	5.6	5.4
6.0	6.1	6.2	6.0

two positions give an estimate of less asphalt present, however, this is usually not a large enough difference to claim significance.

The two ensuing projects indicated very close correlation of the asphalt contents for the different positions. The position averages were claimed to have no significant differences between them and the hypothesis of no real differences between the averages of the different positions is accepted.

Variation

A study of the variation in asphalt content at the three sampling positions indicates significance in σ'^2 is due mainly to the sampling error and material variation. No theoretical differences were claimed for the testing error in the homogeneity of variance comparisons for the several bitumen field checks.

The error attributable to sampling procedure discloses that at several asphalt percentages this portion of the variation is nonhomogeneous between the sampling positions (see Table 6). In several instances where significant differences between the $\sigma_s'^2$ exist, this claim is not critical due to the extremely small values recorded; i.e., in the case of 6.6 percent and 6.7 percent the $\sigma_s'^2$ at the discharge is claimed significant to the $\sigma_s'^2$ at the screw of the paver but at the discharge the values recorded contribute very little to σ'^2. Thus they can be assumed insignificant. With this assumption it can be seen that the only bitumen field checks which have any attributable sampling error at the pugmill discharge are 6.9 percent and 6.5 percent. The increase in the standard deviation due to these values is still quite small.

TABLE 6

Summary of the Components of Variance for Asphalt Contents

F-235(25) & (31)

(a) Testing ($\sigma_t'^2$)

BFC	Discharge	Paver	Pavement
7.5	0.050	0.063	0.022
7.3	0.011	0.060	0.143
7.1	0.014	0.017	0.006
7.0	0.063	0.018	0.042
6.9	0.032	0.044	0.048
6.8	0.055	0.027	0.042
6.7	0.020	0.036	0.021
6.6	0.020	0.049	0.029
6.5	0.036	0.015	0.019

(b) Sampling ($\sigma_s'^2$)

BFC	Discharge	Paver	Pavement
7.5	0.000	0.045	0.029*
7.3	0.000	0.037	0.000*
7.1	0.000	0.026	0.000*
7.0	0.000	0.024	0.000*
6.9	0.011	0.013	0.006
6.8	0.000	0.016	0.022*
6.7	0.001	0.000	0.005*
6.6	0.002	0.000	0.015*
6.5	0.007	0.000	0.020*

(c) Material ($\sigma_a'^2$)

BFC	Discharge	Paver	Pavement
7.5			
7.3	0.015	0.000	0.006*
7.1	0.027	0.000	0.000*
7.0	0.028	0.026	0.050
6.9	0.008	0.029	0.067*
6.8	0.023	0.047	0.025
6.7	0.012	0.023	0.001*
6.6	0.003	0.066	0.000*
6.5	0.000	0.033	0.007*

(d) Overall (σ'^2)

BFC	Discharge	Paver	Pavement
7.5	0.050	0.108	0.051
7.3	0.026	0.097	0.149
7.1	0.041	0.043	0.006
7.0	0.091	0.068	0.092
6.9	0.051	0.086	0.121
6.8	0.078	0.090	0.089
6.7	0.033	0.059	0.027
6.6	0.025	0.115	0.044
6.5	0.043	0.018	0.046

TABLE 6 (cont.)

F-264(8)

BFC	(a) Testing (σ_t^2) Discharge	Paver	Pavement	(b) Sampling (σ_s^2) Discharge	Paver	Pavement
5.7	0.048	0.040	0.026	0.000	0.009	0.019*

BFC	(c) Material (σ_a^2) Discharge	Paver	Pavement	(d) Overall (σ'^2) Discharge	Paver	Pavement
5.7	0.033	0.027	0.021	0.081	0.076	0.066

I-90-8(19)443 U-1

BFC	(a) Testing (σ_t^2) Discharge	Paver	Pavement	(b) Sampling (σ_s^2) Discharge	Paver	Pavement
5.5	0.047	0.022	0.013	0.000	0.017	0.029*
6.0	0.007	0.007	0.072	0.014	0.007	0.003

BFC	(c) Material (T_a^2) Discharge	Paver	Pavement	(d) Overall (T'^2) Discharge	Paver	Pavement
5.5	0.045	0.008	0.006*	0.092	0.047	0.048
6.0	0.011			0.032	0.014	0.075

From visually comparing the σ_s^2's, it is evident the results from the pugmill discharge sampling position are influenced the least by errors in sampling procedure. This allows a better estimate of the actual variation in the material and gives a good average relatively free from errors in sampling the mixture.

The variation in the asphalt material reveals sporadic significance between the sampling positions (see Table 6). All three sampling positions varied greatly in the size of the material σ^2. The discharge samples exhibited the least variability over the bitumen percent from zero to 0.028, while the samples from the screw of the paver varied over a range of 0.066 and the samples from the pavement had a variation in the material ranging over 0.067.

By studying the overall variance, σ'^2, for the various bitumen field checks more definite conclusions may be reached.

Of the eight asphalt field checks recorded, the individual comparisons between sampling positions showed only one analysis to have significance between the discharge and the paver. The pavement σ'^2 was termed greater than the discharge σ'^2 twice at the 5 percent significance level and the opposite significance was claimed once. The paver has a larger σ'^2 than the finished mat at three field checks.

Translating this last paragraph into common terminology by looking for the sampling position having the least variation throughout the bitumen field checks, the discharge has less variation than the two other sampling positions. The finished mat has less variation than the screw of the paver.

In order to have a uniform specification for the various asphalt percentages, the sampling position with the most uniform set of variances is the desirable position, provided the variances are not extremely large, as it allows a good estimate of the average with a minimum amount of sampling.

The pugmill discharge sampling position is favorable in these respects; in addition, its average lies close to the amount of asphalt calculated to be in the mixture.

The overall variances from the other projects in addition to the initial study are also shown in Table 6.

Comparisons between position overall variances for each of these projects resulted in nonsignificant differences indicating they estimate a common true variance.

The average values obtained for a 5.7 percent bitumen field check throughout the Townsend - White Sulphur Springs project gave an $\bar{x} = 5.7\%$ for all three positions. For the West Billings Interchange project the averages for a 5.5 percent bitumen field check were: discharge, $\bar{x} = 5.5\%$; paver, $\bar{x} = 5.6\%$; and pavement, $\bar{x} = 5.4\%$.

A breakdown of the variance components from these two projects shows the component attributable to sampling error to be zero for the discharge sampling position and larger values for the other positions.

Table 6 shows a breakdown of the variance and significance between position variance components.

The results obtained here tend to support findings of the initial project studied both in the average asphalt contents and the values of the overall variances.

Results from this study suggest that the pugmill discharge will give the best indication of the percentage of asphalt in the mixture and the aggregate.

The pugmill discharge samples closely estimate the amount of asphalt said to be present. A sample representative of the proportion of the different sized aggregate should contain the same percentage of asphalt as is contained by the entire unit from which the sample is obtained. Thus, with proper mixing, a sample with the closest asphalt percentage to the amount actually weighed in will also present the best estimate of the aggregate proportions in the unit sampled.

ANALYSIS OF THE -4 + 10 CALCULATION

The -4 +10 value is obtained through subtraction of the percentage of material passing the 10 mesh screen from the percentage of material passing the 4 mesh screen. The value obtained is the amount, in percentage, of the material retained on the 10 mesh screen.

In the -4 + 10 analysis the largest average value was obtained at the pugmill discharge and the smallest average recorded at the finished pavement. This points out that a greater amount of material which passes the 4 mesh screen is retained by the 10 mesh screen in samples from the pugmill discharge than at the other positions. This difference is evident from the analysis of variance which claims the averages to be different at the .05 level of significance.

Using Duncan's multiple range test to determine where the significance recorded actually is, indicated the sample average from the discharge to be significantly different from the paver and the finished pavement sample average. This implies the average found at the pugmill discharge estimates a true mean value which is different from the mean value estimated by the samples from the paver and the pavement. Since nonsignificance was claimed for the comparison between the latter two positions, it is implied that they are estimates of a common true mean value.

The jobs F-264 and I-90-8(19)443 U-1 both developed the same trend as stated in the second paragraph on this page but large enough differences between the sampling position averages on these projects to claim significance were not present.

The variances recorded for the individual positions showed a significance in the overall variation (σ'^2) for the -4 + 10 analysis of the σ'^2 at the

paver to be larger than at the discharge. No other comparisons between position σ'^2 on job F-235 were claimed significant.

F-264(8) demonstrated complete homogeneity of overall variances for the -4 + 10 analysis. I-90, West Billings Interchange, had results of a F-test comparison between overall variances stating the variance at the discharge is greater than the variance recorded at the finished pavement.

This analysis substantiates that segregation of material of certain sizes above the 10 mesh screen exists and is either somewhat replaced by or replaces the material retained on the 10 and 40 mesh screens. It re-emphasizes the fact the results for the 40, 80 and 200 mesh screens are independent of the sampling position.

This conclusion is based on a comparison of the differences between the position averages throughout the mesh screen sizes (see Table 1) or graphically in Figure 1. It is seen the amount of material passing the 40, 80 and 200 mesh screens to be fairly equal regardless of the sampling position, but at the larger screens segregation occurs which is corrected by the 10 and 40 mesh screens.

Thus, if at the 3/8 inch screen a smaller percent of aggregate passes at one sampling position than another, the material which is replaced by the larger aggregate is mainly of the sizes which are retained on the 10 and 40 mesh screens.

Results obtained here are observed to follow closely what is expected by studying the aggregate analysis for these two gradations. A specification drawn for this calculation will be dependent upon the specifications drawn for the aggregate gradations plus the assurance the limits will provide quality pavement construction.

STUDY OF THE DUST RATIO

The dust ratio is computed by the division of the percentage of material passing the 200 mesh screen by the percentage of material passing the 40 mesh screen.

As expected from the gradation analysis results, the average dust ratio at the discharge has the smallest value. This is indicated by the significant differences between the averages recorded at the 40 mesh screen but not at the 200 mesh screen. The resulting averages for the dust ratio are: at the pugmill discharge, $\bar{x} = 39.0\%$; at the paver, $\bar{x} = 39.5\%$; and at the finished mat, $\bar{x} = 40.4\%$. The analysis of variance of the dust ratio claimed these averages to be estimates of the same population mean, μ.

The variances of the three positions indicated a significant difference exists between position overall variances, σ'^2. This is claimed at the 5 percent significance level, but nonsignificance is claimed at the 1 percent significance level.

The position variances shown to be significantly different are the discharge σ'^2 was claimed larger than the pavement σ'^2. No other comparisons were claimed significant.

The averages and σ'^2 are indicated below.

	Discharge	Paver	Pavement
$\bar{x}$	39.0%	39.5%	40.4%
σ'^2	36.1%	34.2%	24.5%

This analysis points out that the proportions of the material passing the 40 mesh screen has less variation in the 40 through 200 mesh screens at the finished mat; i.e., the portion of the material in the samples which

passes the 40 mesh screen will have less variation in the percentage of this total amount which passes the 200 mesh screens.

The dust ratio will be dependent upon the aggregate gradation specifications for the 40 mesh and 200 mesh screens. This analysis is important in finding variation in the dust ratio calculation to allow a specification here to be realistic and usable.

EFFECT OF TEMPERATURE AT LAYDOWN ON THE DENSITY OF THE MIX

For this comparison, temperature readings were taken just prior to compaction of the mix by a steel roller. Core samples were obtained, after the mat had cured, from the corresponding stations on the road before traffic had a chance to enhance the compaction.

The results were analyzed over the range of temperatures and densities found for the Armington - Lewistown project, F-235. The graph of these points is presented in Figure 2.

The straight line curve is referred to as the regression of the density on the temperature and indicates the theoretical relationship of the average density found for a given temperature at laydown. Over the temperature recorded the curve closely projects a straight line with positive slope. As the temperature at laydown is increased the corresponding densities found also increase (within this range of temperature studied). The increase in density is 0.004 pounds per square inch for every 10 degrees Fahrenheit increase in temperature.

The implication of this relationship is that the density of the mix varies directly with the temperature at which the mix is compacted. Thus the higher the temperature at which compaction can be reasonably accomplished the better the density obtainable with ordinary compacting. "Reasonably accomplished" in the last sentence refers to the ability of the mix to compact rather than drastically spread out and lose its form when rolled. It is also assumed that the mix is not heated to the extent that a breakdown of the physical and chemical properties of the asphalt results, causing a loss in strength of the pavement.

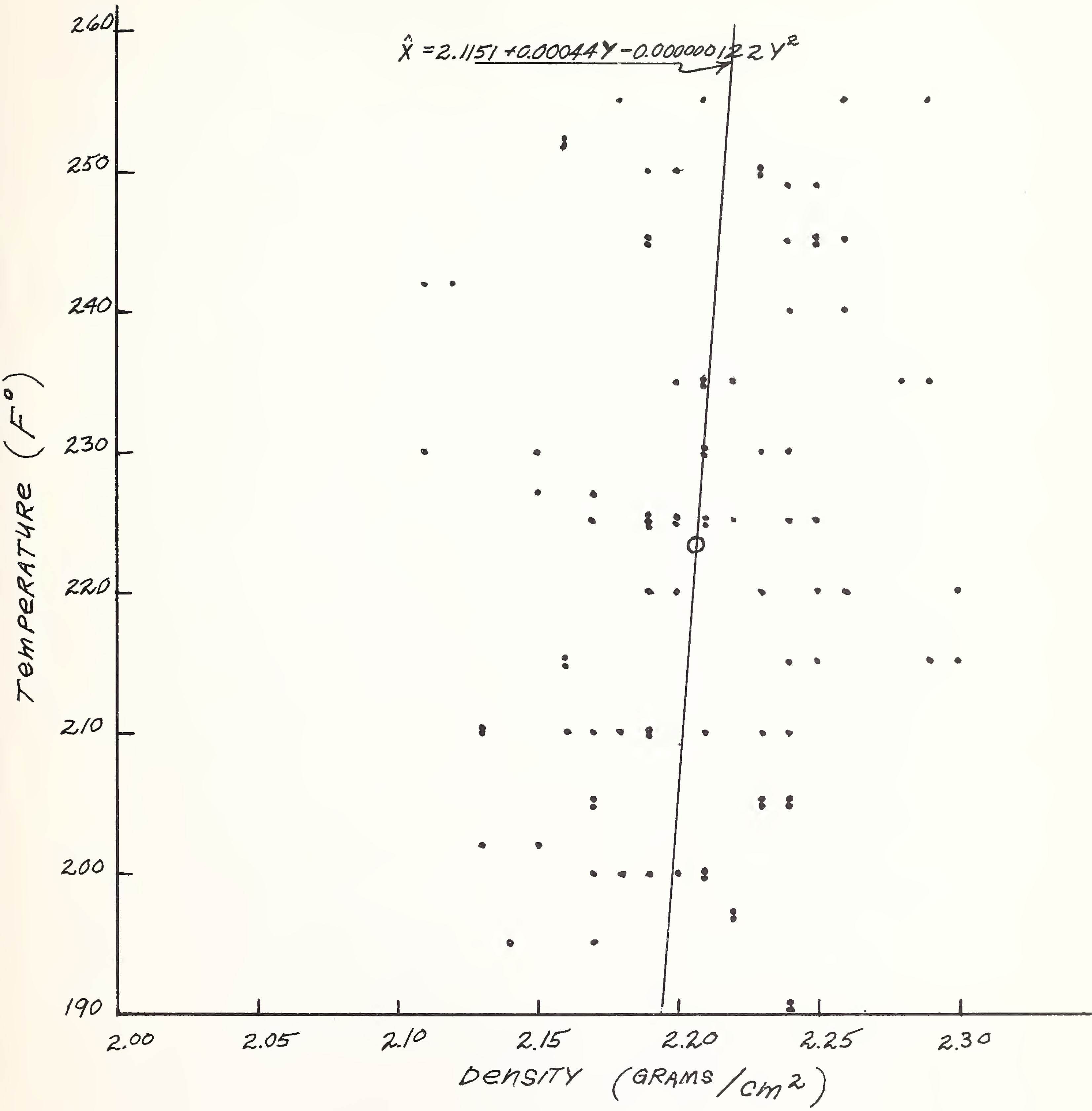
The theory behind the development of the regression presented in Figure 2 is a statistical relationship between an independent and a dependent variable. The density is the dependent variable in the formation of this regression analysis.

This functional relationship supplies estimates of sample means for densities based on populations of the various individual temperatures; i.e., samples taken for an estimate of the density from a "lot" with a controlled temperature, say 250° Fahrenheit, would be expected to average 2.218 on this particular project.

This line gives a prediction of how the material, in relation to the density and the temperature, is expected to react. It is not a plot of individual temperature vs. density comparisons.

Further study on this relationship is recommended at both higher temperatures and a wider range of temperatures to develop the regression curve over a greater range of temperatures. This would also indicate the limitations on the temperature allowable to accomplish the optimum pavement compaction.

FIGURE 2 PLOT OF POINTS AND REGRESSION CURVE OF TEMPERATURE VS. DENSITY



IMMERSION COMPRESSION ANALYSIS

Samples from project I-90-8(19)443 U-1 were obtained for immersion compression testing in the Helena laboratory.

The samples were tested under controlled laboratory conditions and in accordance with procedures outlined in the AASHO manual for this test.

Statistical analysis showed the average compressive strength of a 4 inch by 4 inch cylinder made of this material to be 5937 pounds or 473 pounds per square inch before immersion and 5120 pounds or 408 pounds per square inch after immersion for 24 hours at 140° Fahrenheit. The average strength retained by the immersed cylinders was 87.05 percent.

The variability of the results of both the original compressive strength and the compressive strength after immersion are quite large. This range is shown in Figure 3. Large variability is expressed in the percent of strength retained analysis also.

In Table 7 the number of tests required to predict the true mean with given limits of the estimated average with both 95 percent and 99 percent confidence is presented. If the average percent of strength retained for the plant mix from a given project is found, the true average can be estimated within ±10 percent of the sample average with 95 percent confidence by making five tests; within ±8 percent with 95 percent confidence by making eight tests; with ±6 percent with 95 percent confidence by making thirteen tests and so on.

In order to obtain 99 percent confidence of the true mean being within the given percentage limits of the sample average, five tests must be made to have ±15 percent as limits, eight tests to estimate within ±12 percent, etc.

TABLE 7

Prediction of Tests Required to Estimate on Immersion Compression Tests

$\sigma_{\bar{x}}$ in %	n	$\sqrt{n}$	Confidence Limits for 95%	Confidence Limits for 99%
5	5	2.14	$\bar{\bar{x}} \pm 10\%$	$\bar{\bar{x}} \pm 15\%$
4	8	2.68	$\bar{\bar{x}} \pm 8\%$	$\bar{\bar{x}} \pm 12\%$
3	13	3.57	$\bar{\bar{x}} \pm 6\%$	$\bar{\bar{x}} \pm 9\%$
2.5	19	4.30	$\bar{\bar{x}} \pm 5\%$	$\bar{\bar{x}} \pm 7.5\%$
2	29	5.36	$\bar{\bar{x}} \pm 4\%$	$\bar{\bar{x}} \pm 6\%$
1	115	10.71	$\bar{\bar{x}} \pm 2\%$	$\bar{\bar{x}} \pm 3\%$

$\sigma'_x = 10.71$ $\qquad$ $\sigma_{\bar{x}} = \frac{\sigma'_x}{\sqrt{n}}$

To explain this with an example, if five tests are made a sample average $\bar{x}$ is obtained. Then a 95 percent confidence statement can be made that the true mean lies within ±10 percent of the sample average obtained. To obtain a more precise estimate of the true mean (μ) of the percentage of strength retained, more sample determinations must be made from this lot. The same interpretation is involved for the limits shown in the table for the amount of tests made.

In order to be a useful value, the true mean (μ) should be within ±5 percent of the estimated sample average. Enough samples must be taken and tested to, theoretically speaking, cause the sample average, which is variable, to lie within ±5 percent of the true mean (μ) which is constant for the lot sampled.

To do this with 95 percent confidence, nineteen tests must be made. Each test involves a minimum of four cylinders; thus, seventy-six specimens must be constructed and tested.

The manufacture of this large number of test pieces is very time consuming and involves tieing up expensive equipment while making the test specimens.

It is recommended the merits of this test be studied by supervisory personnel to substantiate the usefulness of this test. If the test is deemed valuable and merits incorporation into the specifications for highway construction, it is then recommended purchase of material to allow rapid completion of this test be considered. Otherwise, this test should be used only when it is deemed necessary to provide auxiliary control for quality highway construction.

Linear correlation between factors affecting the compressive strength of this material were completed in several separate analyses. The following list of conclusions was found from this study.

1. Density and Compressive Strength: r = 0.41. Refer to Figure 5a and b. This correlation indicates that 16 percent of the increase in compressive strength is explained by an increase in the density of the cylinders. An increase in density is, therefore, a contributing factor in the increase in compressive strength.

2. Density and Compressive Strength Retained: r = 0.019. Refer to Figure 5c. The percentage of strength retained shows very little correlation with the density of the cylinders. Thus, approximately a parallel relationship to the axis of the independent variable is expressed on the graph.

The lines for the density and compressive strength both before and after immersion are parallel since no correlation is found in (2) above.

3. -200 Mesh Material and Compressive Strength: r = 0.38. Refer to Figure 5e and f. Over the range of -200 material present from 4.5 percent to 9.5 percent, an increase in the percent of material passing the -200 screen has an effect of increasing the compressive strength of the material.

No material was tested which exceeded these limits so no statement can be made regarding the effect outside this range. Since very few values lie below 5 percent and above 8 percent, these more rigid limits may apply.

The compressive strength in relationship to the -200 mesh material beyond these limits would have to be analyzed with study values above 8

percent and below 5 percent in order to predict whether this linear relationship continues to apply or if a second-degree equation is required to evaluate the relationship.

4. <u>-200 Mesh Material and Compressive Strength Retained:</u> r = -0.03. Refer to Figure 5d. The very small correlation between these factors gives an approximately parallel line to the axis of the independent variable. The negative sign indicates a negative slope and implies a minute decrease in the percentage of the compressive strength retained as the amount of minus 200 material in the cylinder increases.

For the comparisons of the percentage of material passing the 80 mesh screens, the results are much the same as were presented for the -200 material. Corresponding values (correlation coefficients) and material range limitations are: r = 0.017, for the percentage of strength retained, for the compressive strength, r = 0.41 while the material analyzed lies between 8.1 percent passing and 14.1 percent passing the 80 mesh screen.

FIGURE 3 COMPRESSIVE STRENGTH THEORETICAL DISTRIBUTION

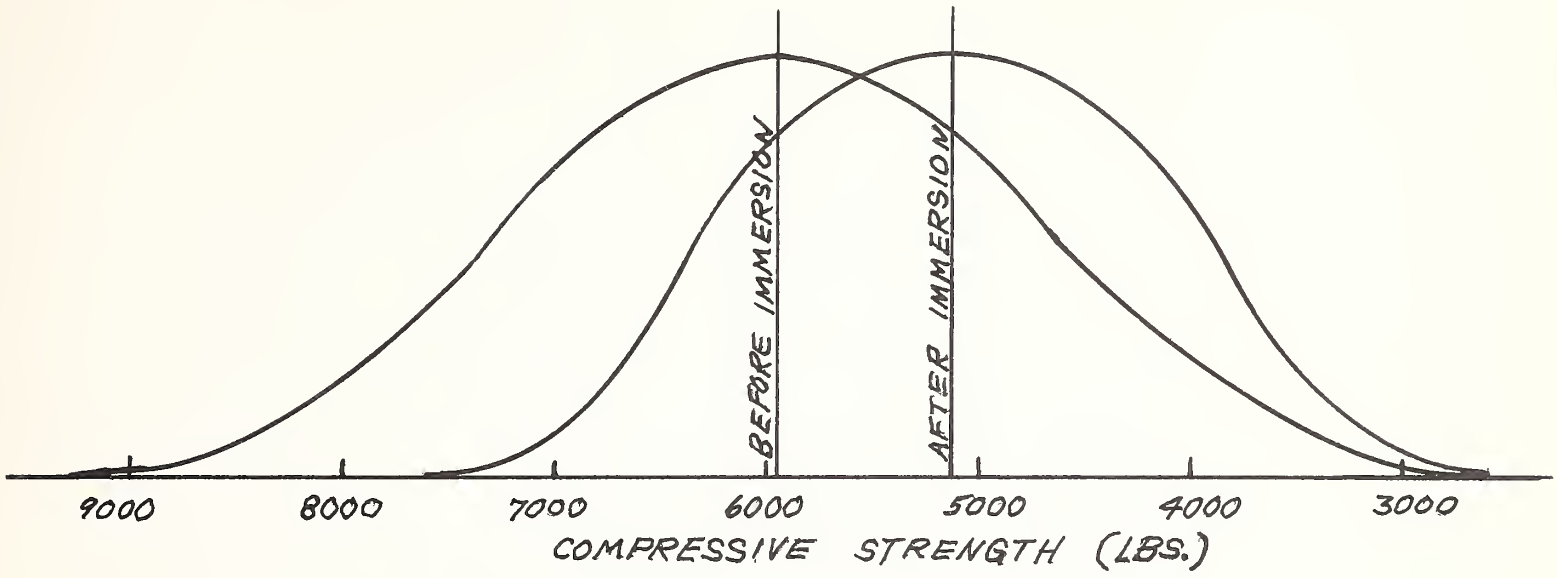


FIGURE 4 STRENGTH RETAINED THEORETICAL DISTRIBUTION

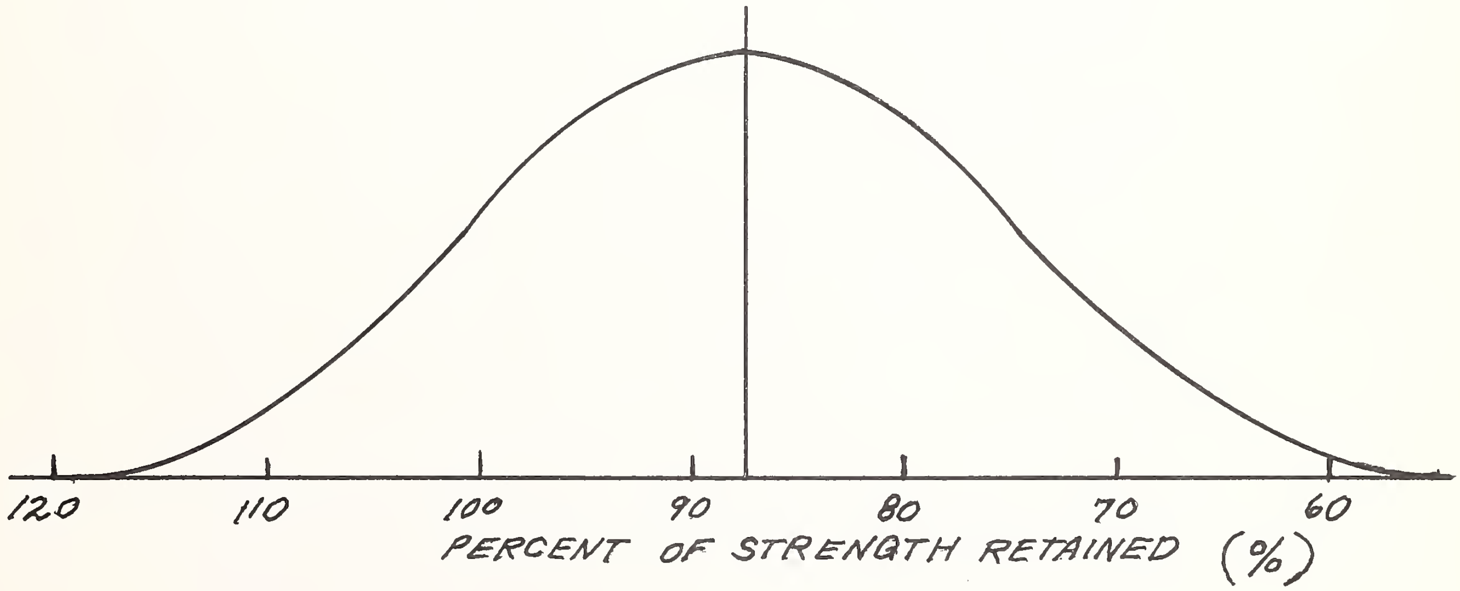
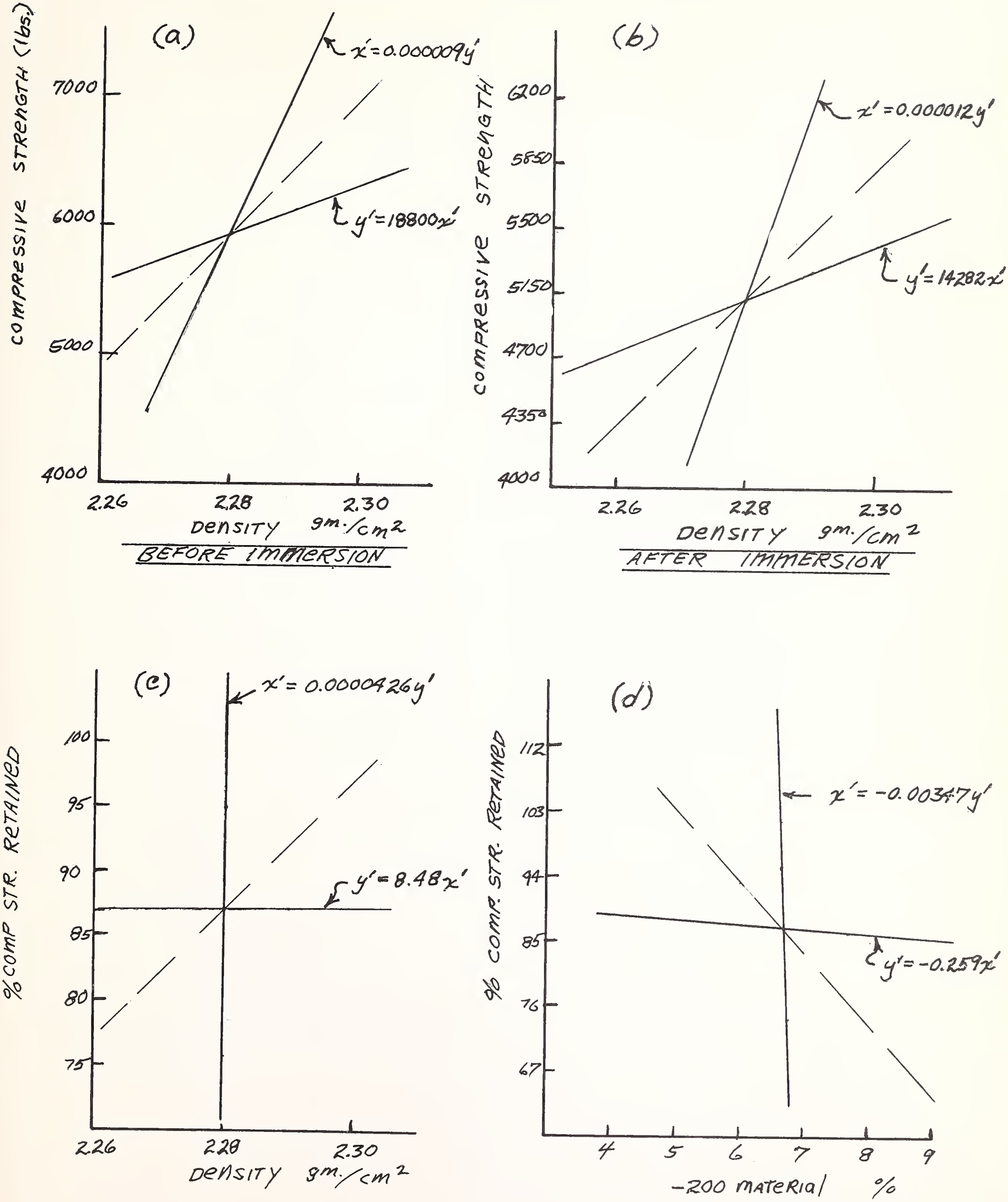
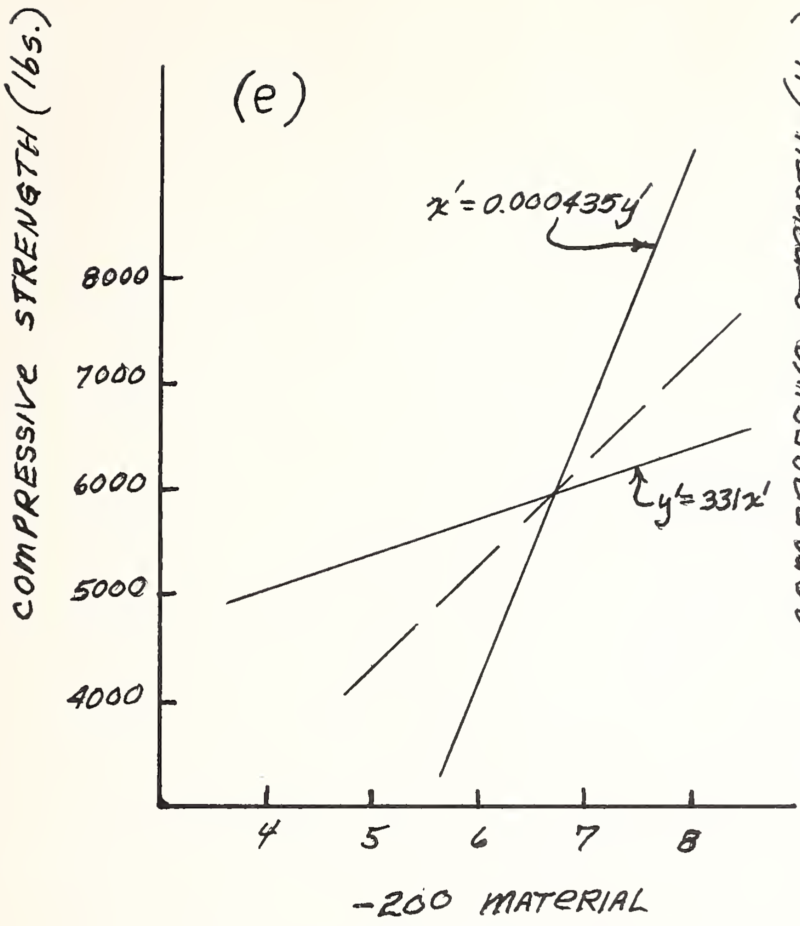


Figure 3 gives the distributions of the actual material strength computed from the immersion compression test results. It shows the specimans before immersion to have a greater variability than the specimans which were tested after 24 hour immersion.

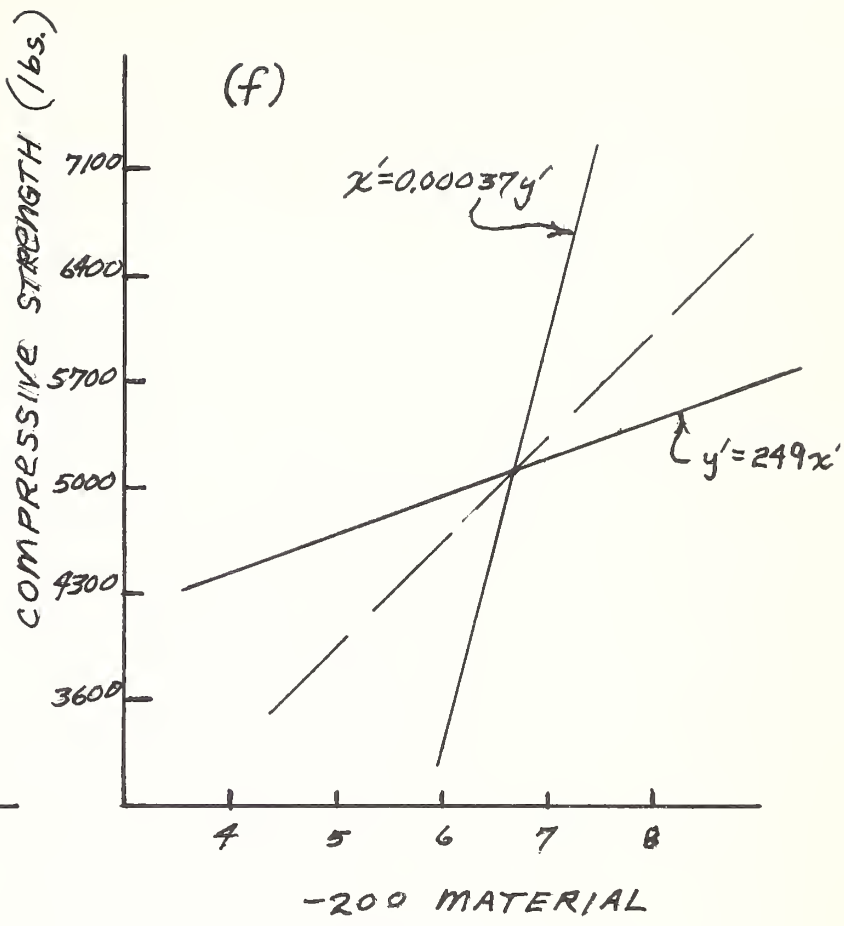
Figure 4 gives the percentage of strength retained. This is computed as the compressive strength after immersion divided by the compressive strength before immersion. The large variation, here, explains the difficulty in obtaining precise results unless a large number of specimans are tested.

FIGURE 5 A MEASURE OF INTENSITY OF ASSOCIATION





BEFORE IMMERSION



AFTER IMMERSION

CONCLUSIONS

1. The values obtained from the extraction of plant mix samples are dependent upon the sampling position for the 1/2 inch, 3/8 inch, 4 and 10 mesh screens.

Differences between the averages for these mesh screen results are sufficiently large enough to require a definite sampling position be adhered to in order to prevent erroneous acceptance or rejection of the mixed material.

2. The largest percentage of aggregate passing a screen will be recorded at the pugmill discharge. The screw of the paver will show less aggregate passing a given screen than the pugmill discharge and the least amount of an aggregate passing a given sized screen will be recorded at the finished pavement.

3. For the percentages passing the 3/4 inch, 40, 80 and 200 mesh screens, the position of sampling has little effect upon the results obtained.

4. The variation present between samples from the individual sampling positions indicate, as a whole, the samples from the pugmill discharge have the least variability while samples from the screw of the paver have the greatest variability.

More samples will be required from the sampling position at the screw of the paver than at the pugmill discharge (out of the trucks) for the same precision at each position. This is extremely apparent for the percent passing the 3/8 inch, 4 mesh and 10 mesh screens.

At the 1/2 inch, 40 mesh, 80 mesh and 200 mesh screens a common variance is claimed for the three positions.

5. From the aggregate gradation analyses, the component of variance due to sampling, σ_s^2, was found to be consistently larger at the screw of the paver.

6. The results obtained from a statistical analysis of the asphalt content indicates the values in best agreement with the bitumen field check are from samples obtained at the pugmill discharge. At the other two sampling positions, less asphalt is calculated to be present.

7. The analysis of the -4 + 10 calculation shows differences to exist between position averages, thus indicating results here are dependent on the sampling position.

8. No theoretical differences between the averages of the dust ratio for the three sampling positions were shown. The variance calculated at the finished pavement was smaller than the variances at the pugmill discharge and at the screw of the paver.

9. The temperature at laydown has an effect upon the density of the compacted pavement. An increase in temperature results in a higher density of the pavement for a given compactive effort.

10. Tests on the study of the immersion compression show a large variation present in the results from an individual project causing precise results to be dependent upon a large number of tests.

11. Several factors were indicated to be involved in the immersion compression test results including: density, -80 and -200 mesh material.

RECOMMENDATIONS

1. One sampling position should be chosen from which to sample plant mix since the results obtained are dependent upon the position of sampling. At the pugmill discharge from the bed of the trucks is the position concluded to give the best representation of the total mix and will allow less sampling to be done for a good estimate.

2. Sampling in a random manner should be accomplished. No specific increments between samples should be used but the project should be sampled throughout.

3. Samples obtained should be large enough to be thoroughly mixed and split in accordance with standard operating procedures to allow proper results.

4. From the truck beds, samples should represent at least three levels of the conical pile in a line from the base to the apex.

5. One person on a project should be familiar with random sampling procedures and assigned to procure the plant mix samples.

6. Contractors bidding on construction projects in Montana should be made aware of the variability of the product so they may realize requirements they must meet to have a high probability of acceptance.

APPENDIX A

Analysis of Variance Performed on Aggregate Gradations from F-235(25) & (31)

Source	df	SS
Positions	t-1	$\frac{X^2_{i\ldots}}{nrs} - \frac{X^2_{\ldots\ldots}}{tnrs}$
Material Error	t(n-1)	$\frac{X^2_{ij..}}{rs} - C - \text{Pos. SS}$
Sampling Error	nt(r-1)	$\frac{X^2_{ijk.}}{2} - \frac{X^2_{ij..}}{4}$
Testing Error	ntr(s-1)	$X^2_{ijkl} - \frac{X^2_{ijk.}}{2}$
Total	ntrs-1	$X^2_{ijkl} - \frac{X^2_{\ldots\ldots}}{ntrs}$

	1/2" MESH				3/8" MESH			
Source	df	SS	MS	F	df	SS	MS	F
Positions	2	32.46	16.23	9.12	2	523.06	261.53	18.73
Material Error	147	262.02	1.78		147	2052.23	13.96	
Sampling Error	150	208.10	1.39		150	672.15	4.48	
Testing Error	300	295.76	0.99		300	924.19	3.08	
Total	599	798.34			599	4171.63		

APPENDIX A (cont.)

Source	4 MESH df	SS	MS	F	10 MESH df	SS	MS	F
Positions	2	1045.63	522.81	21.58	2	497.10	248.55	16.05
Material Error	147	3562.23	24.23		147	2276.84	15.49	
Sampling Error	150	680.28	4.54		150	779.20	5.19	
Testing Error	300	1639.67	5.47		300	437.48	1.46	
Total	599	6927.81			599	3990.62		

Source	40 MESH df	SS	MS	F	80 MESH df	SS	MS	F
Positions	2	28.79	14.39	2.57	2	2.98	1.49	1
Material Error	147	821.15	5.59		147	533.73	3.63	
Sampling Error	150	122.44	0.82		150	93.99	0.63	
Testing Error	300	152.72	0.51		300	128.10	0.43	
Total	599	1125.10			599	758.80		

200 MESH

Source	df	SS	MS	F
Positions	2	2.41	1.20	1
Material Error	147	550.00	3.74	
Sampling Error	150	129.00	0.86	
Testing Error	300	164.47	0.55	
Total	599	845.88		

$F_{.01} = 4.98$ $F_{.05} - 3.15$

APPENDIX B

Analysis of Variance Performed on Asphalt Contents from F-235(25) & (31)

	7.3%				7.1%			
Source	df	SS	MS	F	df	SS	MS	F
Positions	2	0.6328	0.3164	6.55	2	1.4758	0.7379	13.84
Material Error	3	0.1450	0.0483		3	0.1600	0.0533	
Sampling Error	6	0.3562	0.0594		6	0.1618	0.0269	
Testing Error	12	0.8559	0.0713		12	0.1474	0.0123	
Total	23	1.9899			23	1.9450		

$F_{.05} = 9.55$ $F_{.01} = 30.82$

	7.0%				6.9%			
Source	df	SS	MS	F	df	SS	MS	F
Positions	2	0.7596	0.3798	2.07	2	1.2670	0.6335	3.14
Material Error	18	3.2921	0.1829		18	3.6276	0.2015	
Sampling Error	21	0.9203	0.0438		21	1.2927	0.0616	
Testing Error	42	1.7168	0.0409		42	1.7305	0.0412	
Total	83	6.6888			83	7.9178		

$F_{.05} = 4.11$ $F_{.01} = 6.20$

APPENDIX B (cont.)

Source	6.8% df	SS	MS	F	6.7% df	SS	MS	F
Positions	2	2.6911	1.3456	7.24	2	0.1172	0.0586	1
Material Error	36	6.6922	0.1859		21	1.4983	0.0713	
Sampling Error	39	2.2817	0.0585		24	0.5844	0.0244	
Testing Error	78	3.2437	0.0416		48	1.2441	0.0259	
Total	155	14.9087			95	3.4440		

$F_{.05} = 4.11$ $F_{.01} = 6.20$ (6.8%); $F_{.05} = 3.47$ $F_{.01} = 5.78$ (6.7%)

Source	6.6% df	SS	MS	F	6.5% df	SS	MS	F
Positions	2	1.3701	0.6850	5.70	2	0.0705	0.0353	1
Material Error	18	2.1638	0.1202		6	0.4160	0.0693	
Sampling Error	21	0.7469	0.0356		9	0.3332	0.0370	
Testing Error	42	1.3669	0.0325		18	0.4257	0.0236	
Total	83	5.6477			35	1.2454		

$F_{.05} = 5.14$ $F_{.01} = 10.92$ (6.5%)

APPENDIX C

Equation and Plot for Temperature vs. Density Regression Curve

$X = U + a(Y-\bar{y}) + b(Y^2-\bar{y}^2)$

Regression of the Density on the Temperature

$\bar{y} = 223.4° F$

$\bar{x} = U = 2.21$

$a = 0.00044$

REF. FIGURE 2

$b = 0.000000122$

$$X = 2.115 + 0.00044Y - 0.000000122Y^2$$

Y	X
190	2.194
200	2.198
210	2.202
220	2.206
230	2.210
240	2.214
250	2.218
260	2.221

APPENDIX D

TABLE T-1

RANDOM NUMBERS

.576	.730	.430	.754	.271	.870	.732	.721	.998	.239
.892	.948	.858	.025	.935	.114	.153	.508	.749	.291
.669	.726	.501	.402	.231	.505	.009	.420	.517	.858
.609	.482	.809	.140	.396	.025	.937	.310	.253	.761
.971	.824	.902	.470	.997	.392	.892	.957	.640	.463
.053	.899	.554	.627	.427	.760	.470	.040	.904	.993
.810	.159	.225	.163	.549	.405	.285	.542	.231	.919
.081	.277	.035	.039	.860	.507	.081	.538	.986	.501
.982	.468	.334	.921	.690	.806	.879	.414	.106	.031
.095	.801	.576	.417	.251	.884	.522	.235	.398	.222
.509	.025	.794	.850	.917	.887	.751	.608	.698	.683
.371	.059	.164	.838	.289	.169	.569	.977	.796	.996
.165	.996	.356	.375	.654	.979	.815	.592	.348	.743
.477	.535	.137	.155	.767	.187	.579	.787	.358	.595
.788	.101	.434	.638	.021	.894	.324	.871	.698	.539
.566	.815	.622	.548	.947	.169	.817	.472	.864	.466
.901	.342	.873	.964	.942	.985	.123	.086	.335	.212
.470	.682	.412	.064	.150	.962	.925	.355	.909	.019
.068	.242	.667	.356	.195	.313	.396	.460	.740	.247
.874	.420	.127	.284	.448	.215	.833	.652	.601	.326
.897	.877	.209	.862	.428	.117	.100	.259	.425	.284
.875	.969	.109	.843	.759	.239	.890	.317	.428	.802
.190	.696	.757	.283	.666	.491	.523	.665	.919	.146
.341	.688	.587	.908	.865	.333	.928	.404	.892	.696
.846	.355	.831	.218	.945	.364	.673	.305	.195	.887
.882	.227	.552	.077	.454	.731	.716	.265	.058	.075
.464	.658	.629	.269	.069	.998	.917	.217	.220	.659
.123	.791	.503	.447	.659	.463	.994	.307	.631	.422
.116	.120	.721	.137	.263	.176	.798	.879	.432	.391
.836	.206	.914	.574	.870	.390	.104	.755	.082	.939
.636	.195	.614	.486	.629	.663	.619	.007	.296	.456
.630	.673	.665	.666	.399	.592	.441	.649	.270	.612
.804	.112	.331	.606	.551	.928	.830	.841	.602	.183
.360	.193	.181	.399	.564	.772	.890	.062	.919	.875
.183	.651	.157	.150	.800	.875	.205	.446	.648	.685

*Excerpt from BPR correspondence on statistical quality control

PART 2

PROPOSED SPECIFICATION REVISIONS OF SELECTED CHARACTERISTICS

METHOD FOR REVISION OF SELECTED SPECIFICATIONS FOR TYPE 3 PLANT MIX BITUMINOUS SURFACING USING STATISTICAL METHODS

The purpose of this specification revision is to provide a sound basis for acceptance or rejection of a lot by incorporating the established variation present in the production of bituminous hot plant mix with the allowable range of good quality construction.

Using samples obtained from three separate projects throughout Montana, each project being performed by a different contractor, a statistical analysis was pursued on materials incorporated in Type 3 bituminous pavement.

An effort is made to establish guidelines for a revision of present specifications involving statistical controls on selected requirements. A definite method of acceptance or rejection of the material may be accomplished by the incorporation of these controls into the specifications.

It is, in addition, an effort to inform the contractors of the variability of the product they produce and influence them toward placing control over the material such that a very small risk of rejection of the material will be assumed. By initiating control over the material within the specified limits at the time of crushing, fewer problems will arise during paving operations. This will allow more constant production and result in easier fulfillment of their contract requirements.

By realizing the numerous variations that are or may be inherent in the production of aggregates that are to be used in the bituminous mixes, a better understanding of requirements to produce good quality construction is achieved. If these requirements are understood and adhered to, the risk of producing a bad product will be minimized, a more economical operation will result and both the contractor and the consumer will benefit.

A working explanation of the proposed revisions to the specifications follows.

The proposed specifications taken into account the average values of material found on three selected projects having material common throughout Montana, the values found through research to produce maximum density of the material and the variability of the material about the averages recorded.

The basis is that as presented in Figure 1, the lower and upper material limits are presented which are based on sound engineering experience as producing good quality construction.

The most desired value is the midpoint of the range between these limits. From LEL and UEL inward toward the desired average, a distance of $1.645\sigma'$ the specification acceptance limits (A) are drawn. These acceptance limits are based upon the use of the average value of the samples taken. This value is the maximum or minimum sample average allowable which insures the consumer, with minimum risk, that 95 percent of the material lies within the upper and/or lower limits (95 percent control).

If a contractor sets his average for production at the point (A), he stands a 50/50 chance of rejection.

The nearer to the desired average (midpoint of the specifications) production is set, the less the risk of rejection. At points (B), the contractor's risk of having his product rejected is .01 or 1 percent. By setting his average production between points (C), his risk of having the product rejected by the consumer is less than .001 or .1 percent (1/1000 chance of rejection).

If a contractor's production average is set outside the points (A), his risk of rejection of the material is over 50 percent. At the points (D), his risk is 99 percent that the product will be rejected. With the average set at one of these points, the distribution of his product will be such that 25 percent of the material will be outside either the upper or lower engineering limits set forth as allowable material for good quality construction (based on six samples averaged).

The points B, C and D are variable, dependent upon the number of samples averaged.

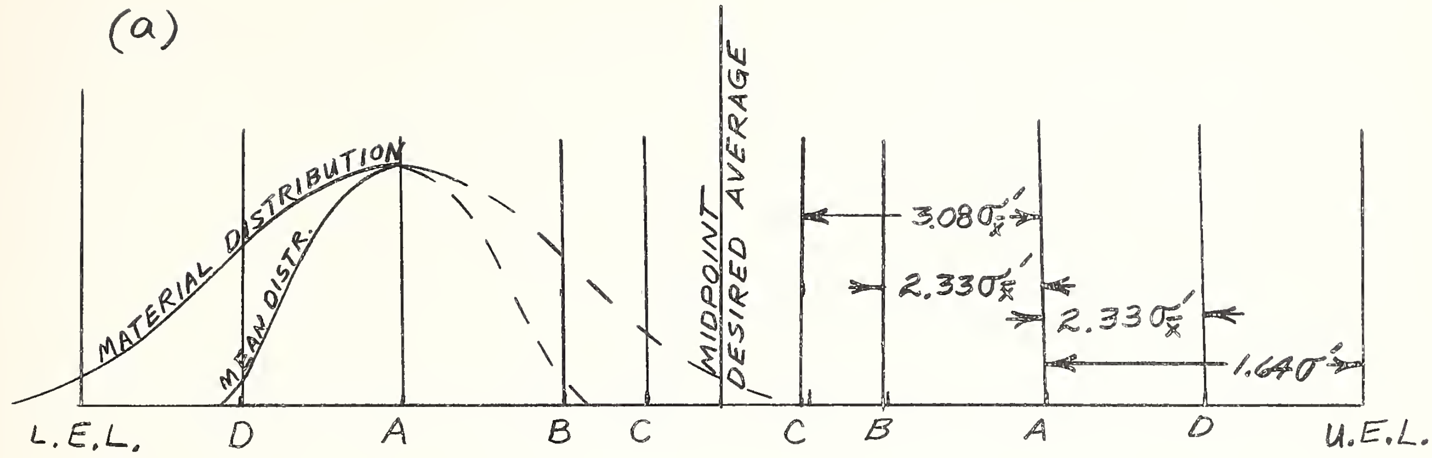
The usefulness of the variability with the number of samples is concerned with the preliminary job mix formula prepared by the testing laboratory. If the material lies within the points (A) but outside one of the points (B) for the standard number of samples determined, the testing agency can recommend extra samples be submitted from the lot being sampled so that if the average production is with points (B) prescribed for a greater number of samples, the product will have a 99 percent chance of acceptance. This extra sampling does not favor the contractor, however, since the points (D) also shift closer to the point (A) and his risk of 99 percent rejection remains the same distance below (A) as point (B) is above (A). The number of samples taken does not affect points (A) since variation between samples, σ_x', is not dependent upon the number of samples as is the estimate of $\sigma_{\bar{x}}'$. Point "A" is the minimum average, regardless of the number of samples taken, which will guarantee that 95 percent of the lot sampled will meet the established engineering requirements. The variable points have to do with the closeness with which μ can be estimated for the lot with the sample average, $\bar{x}_s$, obtained.

The basic sampling plan for Type 3 plant mix aggregate gradations presented is formed on six samples from a lot. The control limits (points B) are given in Table 2. The purpose of this presentation is an effort to provide the contractor with maximum and minimum points as guides in crushing the aggregate and setting his machinery to produce an aggregate which will give 99 percent assurance of being acceptable.

Also presented are the control limits if nine or sixteen samples are taken from a lot.

Thus, if the averages given in Table 2 are achieved in production, the contractor will have less than a one percent chance of having the material rejected since the mean deviation computed indicates only one sample average, $\bar{\bar{x}}_s$, in 100 will fall outside points (A).

FIGURE 1



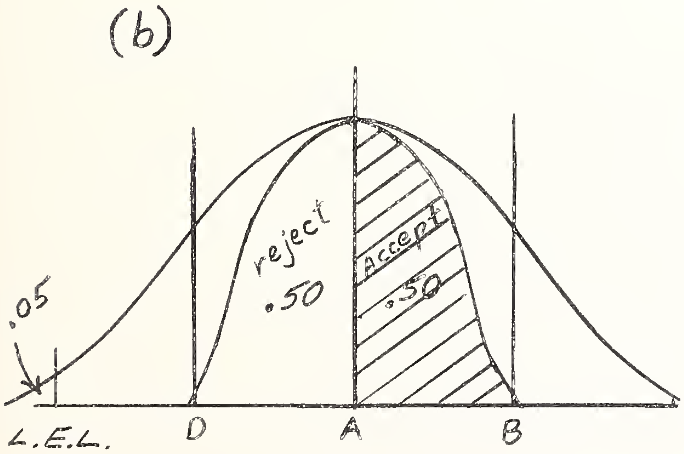
POINTS

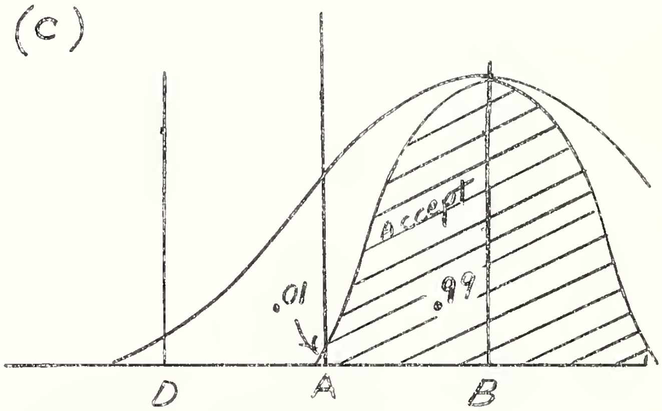
(A) Average, $\bar{\bar{x}}_s$, Specification Limits

(B) 99% Acceptance Production Control Limits

(C) 99.9% Acceptance Production Control Limits

(D) Probability of Rejection 99% if production average is set here.





1-b. The $\bar{\bar{x}}_s$'s will distribute about A symmetrically if A is the average of the lot. 50 percent of the time a $\bar{\bar{x}}_s$ will be obtained to the right of A and the lot will be accepted. 50 percent of the time a $\bar{\bar{x}}_s$ will be obtained to the left of A and the lot will be rejected.

1-c. If the lot average is at B only one $\bar{\bar{x}}_s$ in one hundred will lie below A, the specification limit. If the lot average were set at point D, it is seen that only one $\bar{\bar{x}}_s$ in one hundred would be accepted.

REVISION FOR SPECIFICATIONS OF TYPE 3 PLANT MIX
AGGREGATE GRADATION REQUIREMENTS FOR 3/4" MATERIAL

The basis for acceptance sampling on highway construction projects for the Montana Highway Commission will consist of the average value, $\bar{\bar{x}}_s$, calculated from samples obtained from a part or whole of the project concerned (this sampled region will be termed the "lot").

The limits for individual samples and the extreme average values allowable are based on engineering requirements and research of Type 3 plant mix material so that sound highway construction will be accomplished.

In order to assure good-quality construction with 95 percent of all materials within the established engineering limits, acceptance limits for the sample average obtained from the lot are placed to assure this requirement is met on the whole of the material with minimum risk to the consumer.

Sampling

1. The sampling of Type 3 Bituminous plant mix material will be accomplished in a random manner throughout the project. This requires that no specified intervals between samples are maintained but rather a random number table or substitute random method will be used to locate the moment in production for procuring a sample.

2. Samples for acceptance testing will be obtained from the truck beds as soon after being dumped from the pugmill discharge as practical. All material contained in a sample will be taken from one discharge pile in the truck bed. Three large scoops of material will be obtained from this pile and mixed together. The location of obtaining the three scoops of material will be: 1. near the bottom of the pile; 2. near the middle of the pile; 3. near the top of the pile. The sampling

device should be pushed horizontally into the material at each point and lifted vertically. The sample shall be thoroughly mixed and split in accordance with standard methods. One portion will be shipped to the central laboratory at Helena where final acceptance testing will be accomplished.

To minimize biasness, care should be taken to randomize the locations in a pile from which the ensuing samples are obtained. If one sample is taken from the right hand side of the truck bed, when the next sample is procured, proceed approximately 90 degrees to 120 degrees in a horizontal plane, from where the first sample was obtained, for the next sample, and continue to randomize in this manner throughout the project for all the samples taken.

Working Method of the Specification

The samples will be tested by highway personnel in the central testing laboratory at Helena. The standard number of samples from a "lot" submitted for acceptance testing will be six (6) samples and will be designated as samples for acceptance testing.

An average of each gradation requirement will be obtained. The average will be computed as the sum of the individual values for a certain requirement divided by the number of samples submitted.

The average obtained through this calculation will be compared to the specification limits in Table 1 for compliance.

The part or whole of a project (lot) being studied will be accepted if the average is within the specification limits and rejected as inferior if the sample average lies outside the specification limits.

The maximum sample range allowable is inserted as a guide to the testing agent and the contractor in determining the uniformity of the material achieved during production. If the range of samples exceeds the values recorded, the contractor will be required to place tighter control over his production.

Table 1

3/4" Aggregate Specifications for Type 3 Bituminous Plant Mix Material. (In Percent Passing)

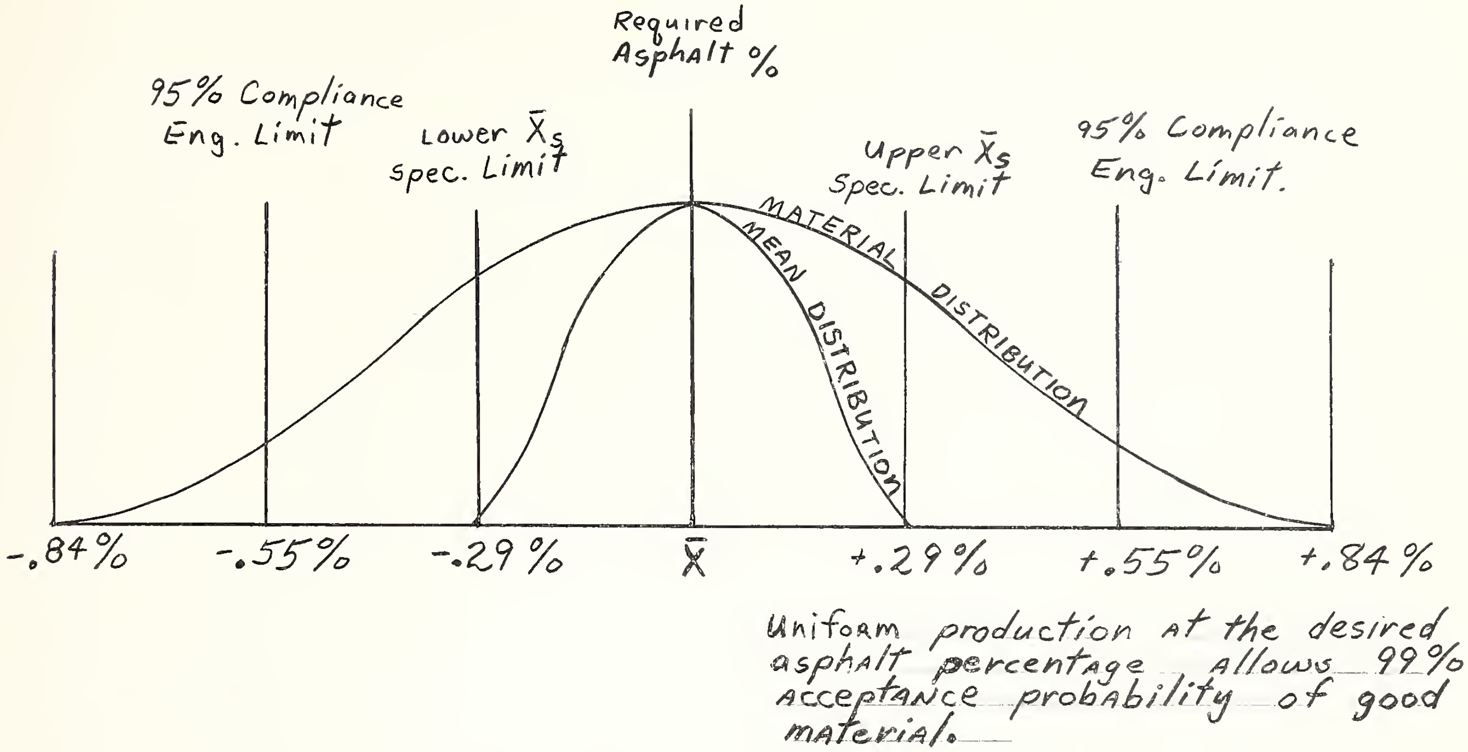
Sieve Size	Engineering Limits	Desired Average Midpoint	$\bar{x}_s$, Specs. Limits on Average	Sample Range Maximum in Percentage
3/4"	100	100	100	0
1/2"	85-100	92.5	87-98	6
3/4"	70-95	82.5	74.10-90.90	13
No. 4	50-70	60	54.5-65.5	15
No. 10	30-50	40	34.9-45.1	16
No. 40	14-28	21	17.4-24.6	11
No. 80	9-19	14	11.3-16.7	7
No.200	2-11	6.5	4.3-8.7	7

TABLE 2

Recommended Control Limits for Setting $\bar{x}'$ of the Production to Assure 99 Percent Probability of Acceptance (In Percent Passing)

Sieve Size	6 Samples		9 Samples		16 Samples	
	L.L.	U.L.	L.L.	U.L.	L.L.	U.L.
3/4"	100	100	100	100	100	100
1/2"	88.1	96.9	87.9	97.1	87.7	97.3
3/8"	76.5	88.5	76.1	88.9	75.6	89.4
No. 4	57.2	62.8	56.7	63.3	56.1	63.9
No. 10	37.7	42.3	37.2	42.8	36.6	43.4
No. 40	19.4	22.6	19.0	23.0	18.6	24.4
No. 80	12.6	15.4	12.4	15.6	12.1	15.9
No. 200	5.6	7.4	5.3	7.7	5.1	7.9

ASPHALT, PERCENTAGE ADDED

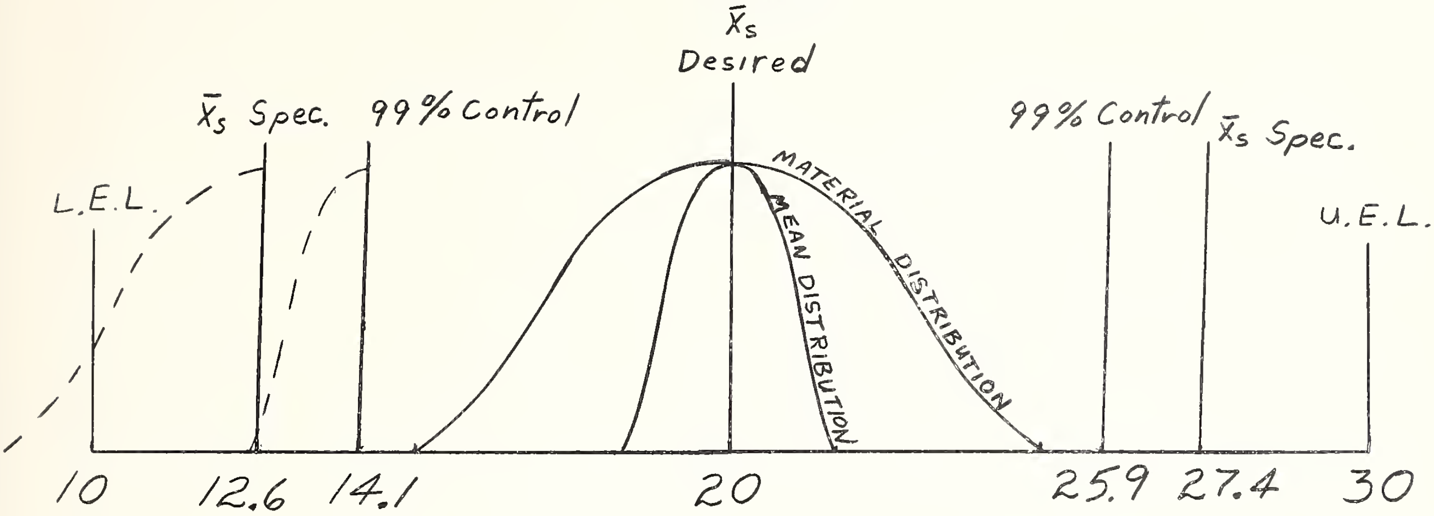


The standard specification for the asphalt percentage added to 3/4 inch aggregate material for use in Type 3 plant mix is based on the average percentage required by the consuming agency.

The contractor will be informed of the required asphalt percentage to add to the aggregate material. From this percentage, an allowable variation in the sample average of six samples from the lot average of ±.29 percent will be considered acceptable material. If a sample average is obtained which is beyond these specification limits, the conclusion is that the contractor did not produce material containing the desired amount of asphalt.

The acceptance samples for asphalt are the corresponding samples used for the acceptance testing of the aggregate gradation.

-4 + 10



The -4 + 10 calculation will have as a basis for acceptance the values from the 4 and 10 mesh screens from the samples designated as acceptance samples for the gradation sieve analysis.

Desired average, 20%, or as computed by preliminary job mix formula.

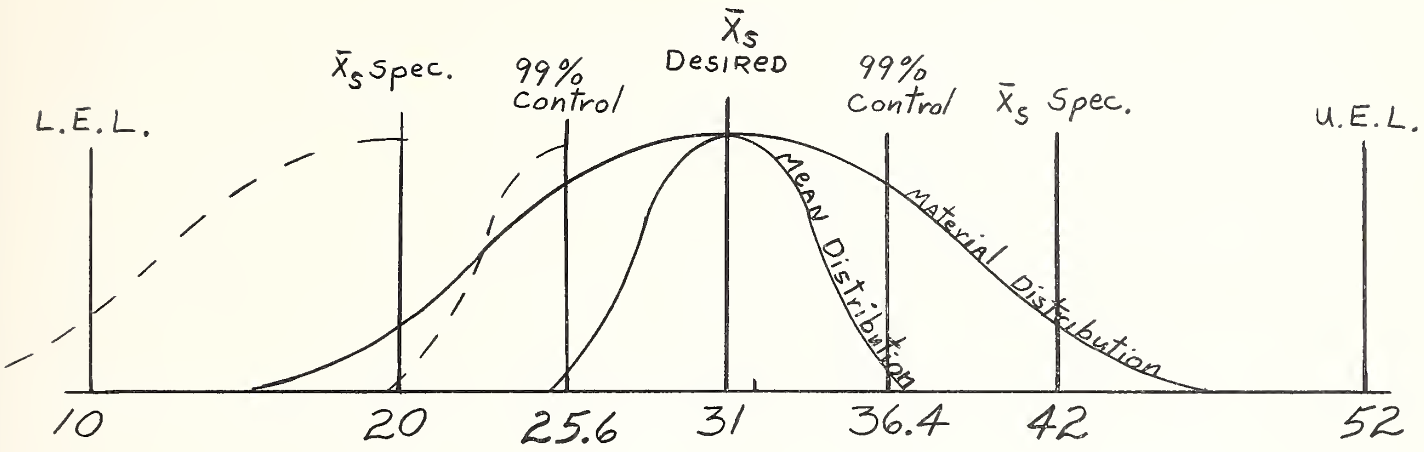
Specification limits, 12.6 to 27.4 in percentage.

Engineering limits, 10 to 30%.

99 percent acceptance control limits, 14.1 to 25.9%.

Recommended maximum range allowable from one individual project, 9%.

DUST RATIO



The Dust Ratio will be figured for each of the samples designated as acceptance samples as the ratio (in percentage) of the percent passing the 200 mesh screen to the percent passing the 40 mesh screen.

The average of the dust ratio calculations will be the basis for acceptance or rejection of material for this specification.

Desired average, 31%, or as computed by preliminary job mix formula.

Specification limits, 20 to 42 in percentage.

Engineering limits, 10 to 52%.

99 percent acceptance control limits, 25.6 to 36.4%.

Recommended maximum range allowable from one individual project, 30%.

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